

**A CORRELATION ANALYSIS OF THE 1000-500
MB THICKNESS TENDENCY**

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A CORRELATION ANALYSIS OF
THE 1000 - 500 mb THICKNESS TENDENCY

by

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ABSTRACT

A correlation analysis of a thickness tendency equation including heating and vertical motion terms was carried out. One of the main purposes of the investigation is to provide a firmer foundation for a 1000-500 mb thickness forecast scheme.

A large data sample was used and single and multiple linear coefficients were calculated. These were computed for a wintertime situation with separate analyses for Atlantic and Pacific areas.

The resulting correlation coefficients for the advection, vertical motion and heating terms gave substance to the hypothesis that the observed change in thickness may be fairly well approximated by the change due to horizontal advection only. The vertical motion term gave a smaller but significant correlation, while heat exchange terms did not correlate significantly.

The author wishes to express his appreciation to Professor G. J. Haltiner for his guidance and encouragement, to Mrs. Jean Bow of the computer center at the U. S. Naval Postgraduate School, for her help in Fortran programming, and especially to Mr. James R. Clark of Meteorology International, Inc., for his assistance in data collection and map reproduction. The author also wishes to express appreciation to the U. S. Naval Fleet Numerical Weather Facility for making their data and computer facility available for this study.

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LIST OF SYMBOLS

Symbol	Definition
\overline{A}	Horizontal advection of thickness
A_n	Noon altitude of the sun (degrees)
C	Cloudiness (in tenths of the sky)
e_a	Water vapor pressure of air (mb)
e_w	Saturated water vapor pressure at the temperature of the water surface (mb)
h	1000-500 mb thickness
\dot{h}	Combined local change of thickness and estimated horizontal advection
Δh	12-hour change of thickness
$\frac{\partial h}{\partial t}$	1000-500 mb thickness tendency
\overline{H}	Total heat exchange over 12-hour period
L_t	Latent heat of evaporation
\dot{Q}	Non-adiabatic heating term
Q_b	Effective back radiation from the sea surface
Q_e	Transfer of latent heat of evaporation
Q_h	Convection of sensible heat to and from the atmosphere
Q_n	Local heat exchange
Q_r	Reflection back from the sea surface (albedo)
Q_s	Total incoming radiation
T_a	Temperature of the air
T_w	Temperature of the sea surface
t_o	Time of map from which grid is obtained
t_d	Length of the day from sunrise to sunset (minutes)

Symbol	Definition
U_o	Relative Humidity
V	Wind speed
\vec{V}	Wind velocity
\bar{w}	Vertical motion term
α	Specific volumn of air
$\bar{\alpha}$	Average solar altitude (degrees)
ψ	Stream function field
σ	Static stability parameter
ω	Vertical motion in (x,y,p,t) coordinates

1. INTRODUCTION

The ability to produce analyses and prognoses of weather maps by numerical methods using high speed digital computers on an operational basis is now a reality. Most of the efforts in numerical weather prediction have been in relation to the pressure and temperature fields; however some pioneering attempts have been made to predict precipitation, clouds and visibility.

Perhaps the most successful forecasts have been of the 500-mb contours. However, somewhat less success has been achieved in obtaining a good surface or 1000-mb prognosis. Many schemes have been tried with varying degrees of success. One method that has a great deal of promise makes use of the 500-mb and 1000-500 mb thickness prognoses to obtain a 1000-mb forecast. The U. S. Naval Fleet Numerical Weather Facility (FNWF) has utilized an empirically adjusted advective technique for thickness prediction. A more complete thickness forecast model including vertical motion, heating and friction is presently under investigation by Professor G. J. Haltiner of the U. S. Naval Postgraduate School. This program utilizes a thickness tendency derived from the first law of thermodynamics and is shown in a subsequent section of this paper. In some of the earlier applications of this equation some of the terms have been omitted by way of simplification because of the lack of information necessary to calculate these terms, for example, diabatic heating. Recently FNWF has made computations of the heat exchange on a regular basis. With this data now available it is appropriate to consider whether a better estimate of a thickness tendency might be obtained if more terms of the equation were retained and fewer simplifying assumptions

made.

The purpose of this investigation is to conduct a first step in a determination of the usefulness of this equation, that is, to statistically correlate the observed 1000-500 mb thickness changes with estimates of the various terms in the thermodynamic equation. As shown by Panofsky and Brier [8] linear correlation coefficients give a measure of association between two variables which does not depend upon any arbitrary choice of units by which the original variables were measured. From the correlation coefficients obtained here each term will be examined as to its relation to the observed thickness change and its significance as a predictor. From these results the value of this equation in a prediction scheme can be estimated.

2. AREA OF INVESTIGATION

FNWF routinely analyzes data over the Northern Hemisphere on a 63 x 63 grid, with a grid distance of 381 KM.

As shown later in this paper the scheme used in obtaining upwind points for data extraction was designed for use on a 22 x 22 grid extracted from any section of FNWF's 63 x 63 grid. The total heat exchange calculations were originally derived for use over the oceans only, however FNWF calculates this term over the whole grid, and then plots only the ocean points. Because the land area points were to be kept at a minimum, all available values of the heat exchange were used. The known decrease in the accuracy of the value over land as compared to that over the ocean nevertheless was accepted in this study and recognized as a possible source of error.

Due to the facts mentioned above two different areas of 22 x 22 grid size were selected for this study. These areas were chosen because most of the grid is oceanic with a minimum of continental area.

Area 1, which will be referred to as the Atlantic area, is shown in figure 1. This area includes the North Pole and the Gulf Stream and has a minimum of equatorial area; the latter is near the boundary of FNWF's grid where results are considered to be less accurate.

Area 2, which will be referred to as the Pacific area, is shown in figure 2. This area is almost entirely oceanic, but does contain more of the equatorial or boundary area. These areas will be treated separately and the correlation coefficients will be calculated independently.

3. BACKGROUND

The thickness prediction equation may be derived in the following way. The first law of thermodynamics can be written

$$\dot{Q} = c_p \left(\underbrace{\frac{\partial T}{\partial t}}_{i} + \underbrace{V \cdot \nabla T}_{iii} + \underbrace{\omega \frac{\partial T}{\partial p}}_{iv} \right) - \underbrace{\alpha \omega}_v \quad (1)$$

Combining the equation of state and the hydrostatic equation gives

$$T = - \frac{g p}{R} \frac{\partial z}{\partial p} \quad (2)$$

Substituting (2) into (1) in terms (ii) and (iii) gives

$$\frac{\dot{Q}}{c_p} = - \frac{g p}{R} \frac{\partial}{\partial t} \left(\frac{\partial z}{\partial p} \right) - \frac{g p}{R} V \cdot \nabla \left(\frac{\partial z}{\partial p} \right) + \omega \left(\frac{\partial T}{\partial p} - \frac{RT}{c_p p} \right) \quad (3)$$

Rearranging, we have

$$\frac{\partial}{\partial t} \left(\frac{\partial z}{\partial p} \right) = - V \cdot \nabla \left(\frac{\partial z}{\partial p} \right) + \frac{R \omega}{g p} \left(\frac{\partial T}{\partial p} - \frac{RT}{c_p p} \right) - \frac{\dot{Q} R}{c_p g p} \quad (4)$$

Integrating between 1000 and 500 mb

$$\frac{\partial h}{\partial t} = - \int_{1000}^{500} V \cdot \nabla \left(\frac{\partial z}{\partial p} \right) dp + \int_{1000}^{500} \sigma \omega dp - \int_{1000}^{500} \frac{\dot{Q} R}{g p c_p} dp \quad (5)$$

where

$$\sigma = \frac{R}{g p} \left(\frac{\partial T}{\partial p} - \frac{RT}{c_p p} \right) \quad (6)$$

Now integrating over a 12-hour time period gives

$$\Delta h = \int_0^{12} \int_{1000}^{500} \underbrace{V \cdot \nabla \left(\frac{\partial z}{\partial p} \right)}_{\bar{A}} dp dt + \int_0^{12} \int_{1000}^{500} \underbrace{\sigma \omega}_{\bar{W}} dp dt - \int_0^{12} \int_{1000}^{500} \underbrace{\frac{\dot{Q} R}{g p c_p}}_{\bar{H}} dp dt \quad (7)$$

The purpose of this investigation is to correlate the 12-hour thickness changes with numerical approximations of the terms constituting the right hand side of equation 7. Thus Δh will be correlated with estimated mean values of the horizontal advection, \bar{A} , the vertical motion term, \bar{W} , and the total heat exchange, \bar{H} , for the 12-hour period. This relationship may be written

$$\Delta h = \bar{A} + \bar{W} + \bar{H} \quad (8)$$

The coefficients of the terms in equation 7 can be considered as merely constants of proportionality and thus can be omitted in the statistical evaluation.

The parameter σ as defined here differs slightly from the value of σ used by FNWF. However, here again the difference can be considered essentially as a constant of proportionality and will not affect this study.

4. DATA COLLECTION

The basic data for this study was obtained for the three-day period 9 to 11 February 1966 from the Fleet Numerical Weather Facility.

The initial fields utilized were the SD-500 field which is the disturbance component (perturbation) of the 500-mb height field, the SR-500 field which is the residual component (basic flow) of the 500-mb height field, the SD-1000 field which is the disturbance component at the 1000 mb level and the SR-1000 field which is the basic flow at the 1000-mb level.

These fields were used in a routine originally designed for the interpretation of meteorological satellite observations as developed by Nagle, Clark and Holl [7] and modified by Clark for use in obtaining the advective change in thickness, \bar{A} . The scheme entails generation of stream function fields, Ψ , figures 3 and 4, from the SD and SR fields averaged over the 1000-500 mb layer. By a timewise interpolation of the 12-hour distributions, hourly distributions of Ψ were obtained which would act as evolving frame- of- reference steering fields. From these Ψ fields a horizontal velocity distribution was computed. This wind was based on the geostrophic approximation and in this case was the mean wind in the layer.

At this time the 12-hourly winds for a 22 x 22 subsection of the 63 x 63 grid were extracted. This subregion was then interpolated in both time and space to give hourly winds into an expanded 44 x 44 array based on the 22 x 22 section. This maneuver quadruples the number of data points contained in the region.

By utilizing the stream function and the wind field, an upstream

trajectory was projected and the position of a column of air at time $t_0 - 12$ was determined. This was done for each data point in the region. Checks in the program flagged any point whose upstream position was out of the 44×44 grid. This point was then discarded for correlation purposes.

Several steps were involved in the procedure used to determine \bar{A} . Thickness fields, figures 5 and 6, were obtained from FNWF's D-500 and D-1000 fields. These D fields give the difference between the height of the surface (500 and 1000 mb, respectively) and its corresponding standard height. The trajectory scheme was then applied to this field to yield a new parameter, \dot{h} , which is the combined local change of thickness, Δh , and the estimated horizontal advection, \bar{A} . Figures 7 and 8 depict this parameter in the Atlantic and Pacific areas, respectively. The strong gradient in the extreme western section seen in these and subsequent maps was due to the check-flag system discussed previously. These are the areas of inflow where the upstream position was off the grid causing a zero to be inserted. While the zero value was eliminated before correlations were made, the point was plotted as such resulting in tight gradients where none actually exist.

The local or observed 12-hour change in thickness, figures 9 and 10, was produced by subtracting the field at time $t_0 - 12$ from the field at time t_0 . To get an estimate of \bar{A} at each point, Δh was subtracted from \dot{h} ; this was not completed until the format of the data had been changed and the correlation program was in use.

A further modification of the routine allowed \bar{W} to be computed. This vertical motion term was obtained by taking the product of σ and

ω , the vertical motion in (x,y,p,t) coordinates, and averaging in both time and space.

To accomplish this sigma-1 and sigma-3, the static stability for the layers, 1000-750 and 600-750 mb respectively, were utilized. These σ 's were derived from a model by Holl, Bibbo and Clark [2] which is characterized by pressure levels defining a number of layers within which the static stability is independent of pressure.

These terms were multiplied by the ω fields at 850 and 500 mb. FNWF computes these parameters by a numerical solution of a quasi-geostrophic omega equation, as shown by Haltiner, Clarke and Lawniczak [1]. The resulting fields were $\sigma\omega_{850}$, figures 11 and 12, and $\sigma\omega_{500}$, figures 13 and 14. The trajectory scheme was again used to obtain up-wind values of these terms at time $t_0 - 12$ which were then averaged with values at t_0 to yield the 12-hour averages, $\overline{\sigma\omega}_{850}$ and $\overline{\sigma\omega}_{500}$, shown in figures 15, 16, 17 and 18. The final averaging of $\overline{\sigma\omega}_{850}$ and $\overline{\sigma\omega}_{500}$ to obtain \overline{W} was completed by the correlation program itself.

The same procedure was used to obtain \overline{H} . This term was derived from the fields of Q_n , the total air-ocean interchange as produced by FNWF shown in figures 19 and 20. The computation program of the total heat exchange by numerical methods and its adaption to the computer evolved from earlier manual methods developed by Laevastu [4]. The heating function was obtained from the following equation:

$$Q_n = Q_s - Q_r - Q_b - Q_h - Q_e \quad (9)$$

where all Q's will be expressed in units of g-cal cm^{-2} (24 hr.)⁻¹.

Because of the relative newness of the computerized form of this product

each term will be briefly discussed.

The insolation, Q_s , is calculated from the equation

$$Q_s = 0.14 A_n t_d (1 - 0.0006 C^3) \quad (10)$$

which takes into account the total time that the sun is above the horizon, t_d , the noon altitude of the sun, A_n , and a cloudiness factor, C . Since it is virtually impossible to take into consideration various types of clouds and their different effects on the insolation, Laevastu [3] devised an average cloudiness factor which requires only a knowledge of total cloud tenths. The results give a reasonable estimate of the total incoming radiation.

The albedo, Q_r , is an estimate of the radiation reflected from the surface. Laevastu [5] statistically determined an empirical formula for calculating this term.

$$Q_r = 0.15 Q_s - (0.01 Q_s)^2 \quad (11)$$

This formula is valid only for daily calculations. A simplified formula for the computation of short term (hourly or 3-hourly) albedo is

$$Q_r = Q_s \frac{300}{\bar{\alpha}}, \quad \bar{\alpha} = \text{Average solar altitude} \quad (12)$$

The effective back radiation, Q_b , is the long wave radiation given off by the sea surface. This represents a heat loss at the surface

$$Q_b = (297 - 1.86 T_w - 0.95 U_o)(1 - 0.0765 C) \quad (13)$$

and makes use of a linear formula of Lonnquist [6] which is corrected by Moeller's cloudiness factor.

The convective transfer of sensible heat, Q_h , was obtained from

$$Q_h = 39 (0.26 + 0.77 V)(T_w - T_a), \quad T_w > T_a \quad (14)$$

when heat is transferred from the water to the air; and

$$Q_h = 3 V (T_w - T_a), \quad T_w < T_a \quad (15)$$

when heat is transferred from the air to the water.

The latent heat transfer, Q_e , is that heat addition or loss due to evaporation or condensation. Lavastu [5] shows that a modified formula of Rohwer has been found to be most accurate in estimating evaporation; namely,

$$Q_e = (0.26 + 0.77 V)(0.98 e_w - e_a), \text{ if } 0.98 e_w > e_a \quad (16)$$

A modified form of this equation can be used for condensation at the sea surface,

$$Q_e = 0.077 V (0.98 e_w - e_a) L_t, \text{ if } 0.98 e_w < e_a \quad (17)$$

To calculate these terms and get a total heat exchange product certain basic synoptic numerical analyses must be available. These are: Surface winds, surface air temperature and water vapor pressure and clouds. These are all routinely produced at FNWF.

By utilizing the trajectory program again, the $t_0 - 12$ values of Q were obtained. Averaging over the 12 hours produced \bar{H} , figures 21 and 22. No further data was needed.

5. OBJECT AND METHOD INVESTIGATION

The purpose of this investigation was two-fold. An attempt was made a) to statistically correlate the observed change in thickness with estimated values of the terms on the right hand side of equation (7) and b) to estimate the significance of each term in a prediction scheme.

To accomplish this a multiple regression and correlation analysis, the BMD03R programmed for the CDC 1604 electronic computer and converted for COOP MONITER Fortran 63, was utilized. This program will perform linear-multiple correlation analysis on data in any combination by allowing the designation of a dependent variable and deletion of sets of independent variables. This can be done as many times as desired.

At the completion of the data collection phase there were five parameters stored for each data point over a total of 8229 Atlantic and 6739 Pacific points which were considered good for correlation purposes. These variables were: (1) \dot{h} ; (2) $\overline{\sigma w}_{850}$; (3) $\overline{\sigma w}_{500}$; (4) \overline{H} ; and (5) Δh . To place this data in a form appropriate for the BMD program the format had to be changed from a row-wise listing to a column presentation. After accomplishing this, spot checks were made to ensure that the data had not gotten out of phase during the transformation.

Since the parameters \overline{A} and \overline{W} had not actually been obtained as yet, the transgeneration feature of BMD03R was used. This allows for the generation of new variables by performing certain mathematical operations on the original variables. Here \overline{A} , variable 6, was obtained by the subtraction (1) - (5) = (6) and \overline{W} , variable 7, was produced from $[(2) + (3)]_{\frac{1}{2}} = (7)$. The data was then ready for the correlation analysis.

6. RESULTS AND DISCUSSION

The data was divided into Atlantic and Pacific regions with identical calculations made for each area. Initially, correlation analyses were carried out to show relationships between pairs of variates. Many combinations of independent and dependent variables were used. The results are shown in Tables 1 and 2.

After examining the figures, multiple linear correlations were made. This was done by progressively adding the term from equation (8) with the highest partial correlation coefficient.

As a side operation, a multiple correlation analysis was made on the terms of the equation

$$\dot{h} \propto \bar{W} + \bar{H}$$

These results are shown in Tables 3 and 4.

The values of R obtained from the Atlantic data were slightly higher than those in the Pacific in almost every case. This can be partially explained by a) the scarcity of reporting stations in the Pacific resulting in larger interpolated areas, and b) the Pacific area contains a larger band of equatorial or boundary region where the analysis is known to be less accurate.

The coefficient obtained in the linear correlation of Δh and \bar{H} was extremely low in both the Atlantic and Pacific.

The coefficient resulting from the correlation of Δh and \bar{W} was lower than expected but was approximately the same in both Atlantic and Pacific.

Δh was correlated with $\bar{\sigma}_{850}$ and $\bar{\sigma}_{500}$ separately to see if it was necessary to obtain \bar{W} or if the value of the parameter obtained at a single level would be sufficient. In the Atlantic there is little

Dependent Variable	Independent Variable	R	R ²
Δh	\bar{A}	.8599	.7394
Δh	\bar{W}	.1936	.0375
Δh	\bar{H}	.0655	.0043
Δh	$\overline{\sigma W}_{850}$	.1729	.0299
Δh	$\overline{\sigma W}_{500}$	.1850	.0342
\bar{W}	\bar{A}	.4513	.2037
\bar{W}	\bar{H}	.2200	.0484
\bar{A}	\bar{H}	.1799	.0324
\dot{h}	\bar{H}	.2425	.0588
\dot{h}	\bar{W}	.5802	.3366

Table 1. Results of non-multiple linear correlation analyses, Atlantic. R is the correlation coefficient and R² is the coefficient of determination.

Dependent Variable	Independent Variable	R	R ²
Δh	\overline{A}	.7967	.6347
Δh	\overline{W}	.1752	.0302
Δh	\overline{H}	.0985	.0097
Δh	$\overline{\sigma W}_{850}$	.2440	.0595
Δh	$\overline{\sigma W}_{500}$	.0825	.0068
\overline{W}	\overline{A}	.2569	.0660
\overline{W}	\overline{H}	.0404	.0016
\overline{A}	\overline{H}	.0962	.0093
\dot{h}	\overline{H}	.0483	.0023
\dot{h}	\overline{W}	.5373	.2886

Table 2. Results of non-multiple linear correlation analyses, Pacific.

Dependent Variable	Independent Variable	R	R ²
Δh	\overline{A}	.8599	.7394
Δh	$\overline{A} + \overline{W}$	.8871	.7869
Δh	$\overline{A} + \overline{W} + \overline{H}$	.8889	.7901
\dot{h}	$\overline{W} + \overline{H}$	.5920	.3505

Table 3. Results of the multiple-linear correlation analysis, Atlantic.

Dependent Variable	Independent Variable	R	R ²
Δh	\overline{A}	.7967	.6347
Δh	$\overline{A} + \overline{W}$	.8562	.7331
Δh	$\overline{A} + \overline{W} + \overline{H}$	.8625	.7439
\dot{h}	$\overline{W} + \overline{H}$	.5418	.2936

Table 4. Results of the multiple-linear correlation analysis, Pacific

difference in the coefficients but in the Pacific, the three differ considerably.

The multiple correlation coefficient in the Atlantic increased from .8599 to .8871 to .8889 as \bar{W} and \bar{H} were added to \bar{A} . The increase in the Pacific was somewhat greater, going from .7967 to .8562 to .8625 as these terms were added. Here the inclusion of the vertical motion is more significant.

The analysis of \dot{h} with \bar{W} and \bar{H} was attempted with the thought that \dot{h} might be used in a cloud forecast scheme currently under study. Although the correlations in both areas are significant, they are certainly not high enough to consider replacing vertical velocities by \dot{h} in a cloud forecasting scheme.

The remaining analyses clearly show no significance and will not be discussed further.

7. CONCLUSIONS AND RECOMMENDATIONS

As a result of this study, which was made using wintertime data only, the following conclusions were reached.

(1) Observed changes in thickness over a 12-hour period are due almost entirely to horizontal advection, at least as approximated in this study. This result lends strong support to the simple advective scheme for predicting thickness which has been used operationally by FNWF during the past several years, i.e.

$$\Delta h \approx \mathbf{V} \cdot \nabla h$$

(2) The vertical motion term, \bar{W} , though of secondary importance, does contribute significantly to the change in thickness and should be retained in a prediction scheme for increased accuracy. Of course, a decision must be made as to whether the improvement in forecasting skill is worth the time and effort necessary to include vertical motion.

(3) The heat exchange term, \bar{H} , as presently being calculated at FNWF and as utilized in this study contributes virtually nothing to the change in thickness and should be omitted in a thickness prediction scheme.

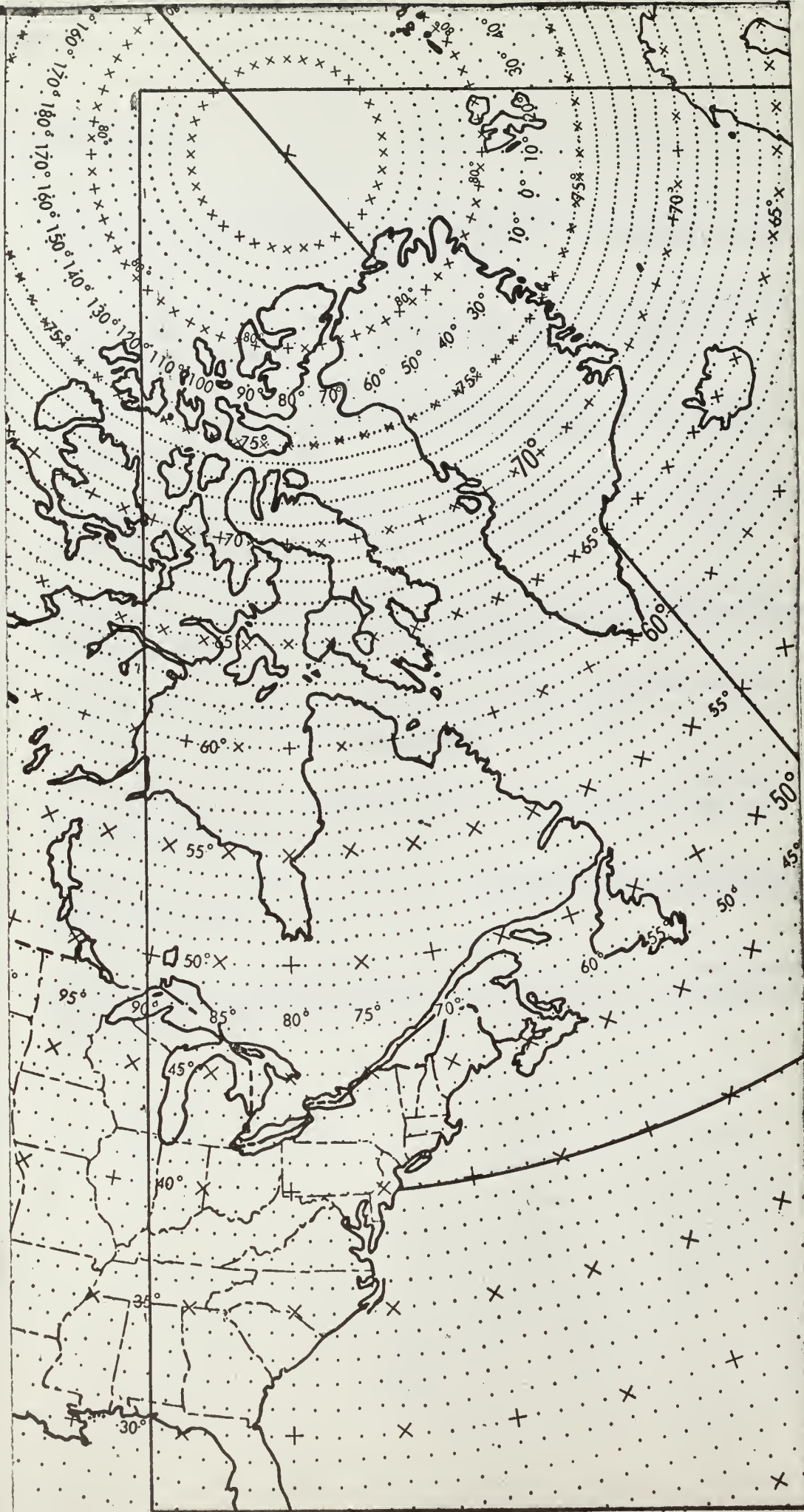
As pointed out earlier, this study dealt only with winter data. An obvious and necessary extension should be the application to data from the other seasons, especially summer.

It is hoped that the results of this study will provide guidance to individuals or groups engaged in the development of thickness prediction schemes.

8. BIBLIOGRAPHY

1. Haltiner, G. J., Clarke, L. C. and Lawniczak, G. E., Jr. Computations of the Large Scale Vertical Velocities. Journal of Applied Meteorology, Vol. 2, No. 2, April, 1963.
2. Holl, M. M., Bibbo, J. P. and Clark, J. R. Linear Transforms for State-Parameter Structure. Meteorology International, Inc., Technical Memorandum No. 1, Edition 2, October, 1963.
3. Laevastu, T. Factors Affecting the Temperature of the Surface of the Sea. Societas Scientiarum Fennica, Commentations Physico-Mathematicae XXVI, 1960.
4. Laevastu, T. Energy Exchanges in the North Pacific; its Relation to Weather and its Oceanographic Consequences, Part I, Hawaii Institute of Geophysics, Report No. 29, 1963.
5. Laevastu, T. Daily Heat Exchange in the North Pacific, its Relation to Weather and its Oceanographic Consequences, Societas Scientiarum Fennica, Commentations Physico-Mathematicae, Vol. 31, No. 2, 1965.
6. Lonnquist, O. Synthetic Formulae for Estimating Effective Radiation to a Cloudless Sky and their Usefulness in Comparing Various Estimation Procedures, Ark. Geofys, 2(12), 1954.
7. Nagle, R. E., Clark, J. R., and Holl, M. M. Test of the Diagnostic-Cycle Routine in the Interpretation of Layer-Cloud Evolution. Monthly Weather Review, Vol. 94, No. 2, February 1966.
8. Panofsky, H. A. and Brier, G. W. Some Applications of Statistics to Meteorology. Mineral Industries Continuing Education, University Park, Penn. 1958.
9. _____, Multiple Regression with Case Combination, BMD03R, Health Science Computing Facility, University of California at Los Angeles, August, 1964.

APPENDIX A



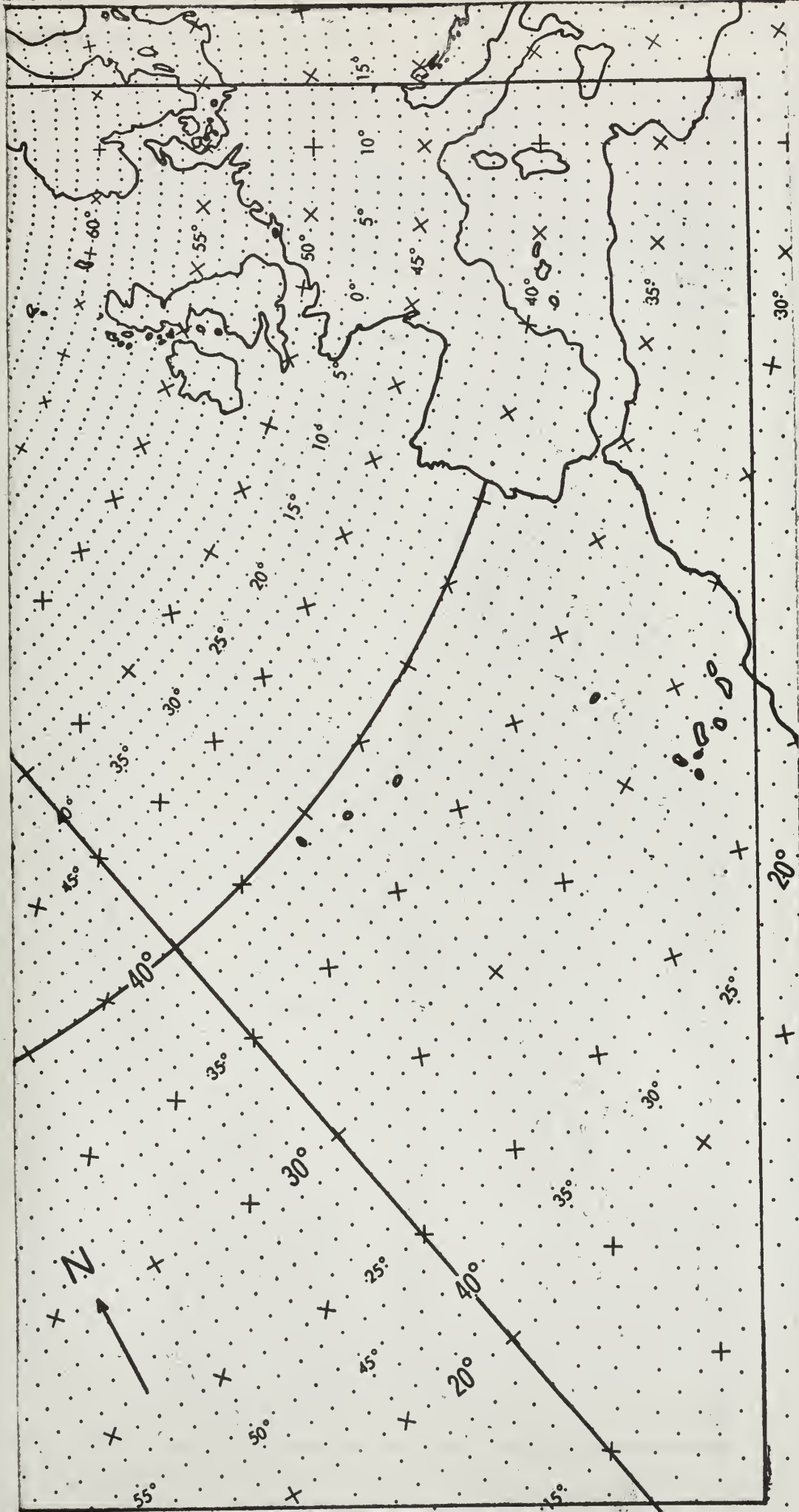
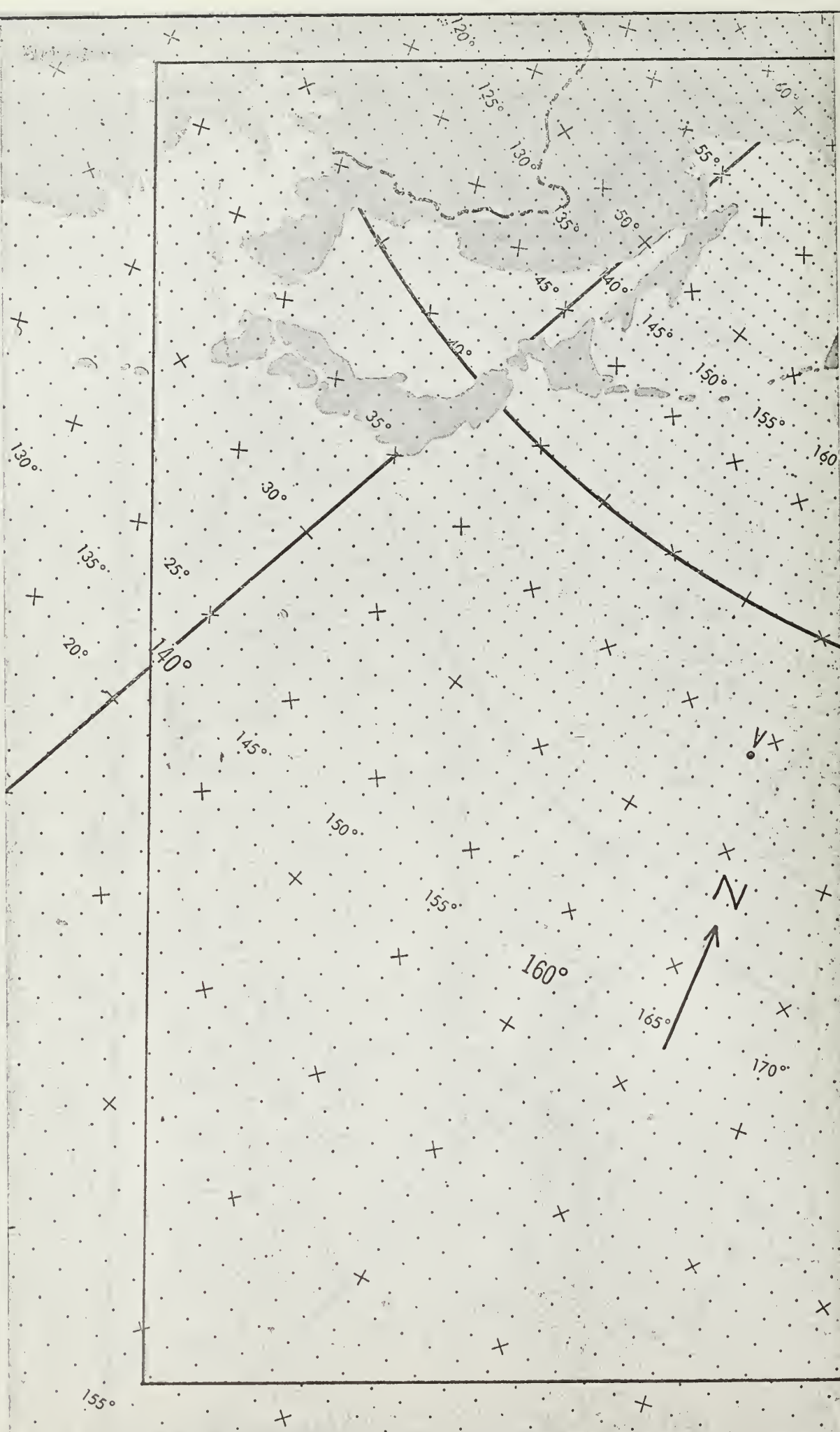


Figure 1 Area of Investigation, Atlantic



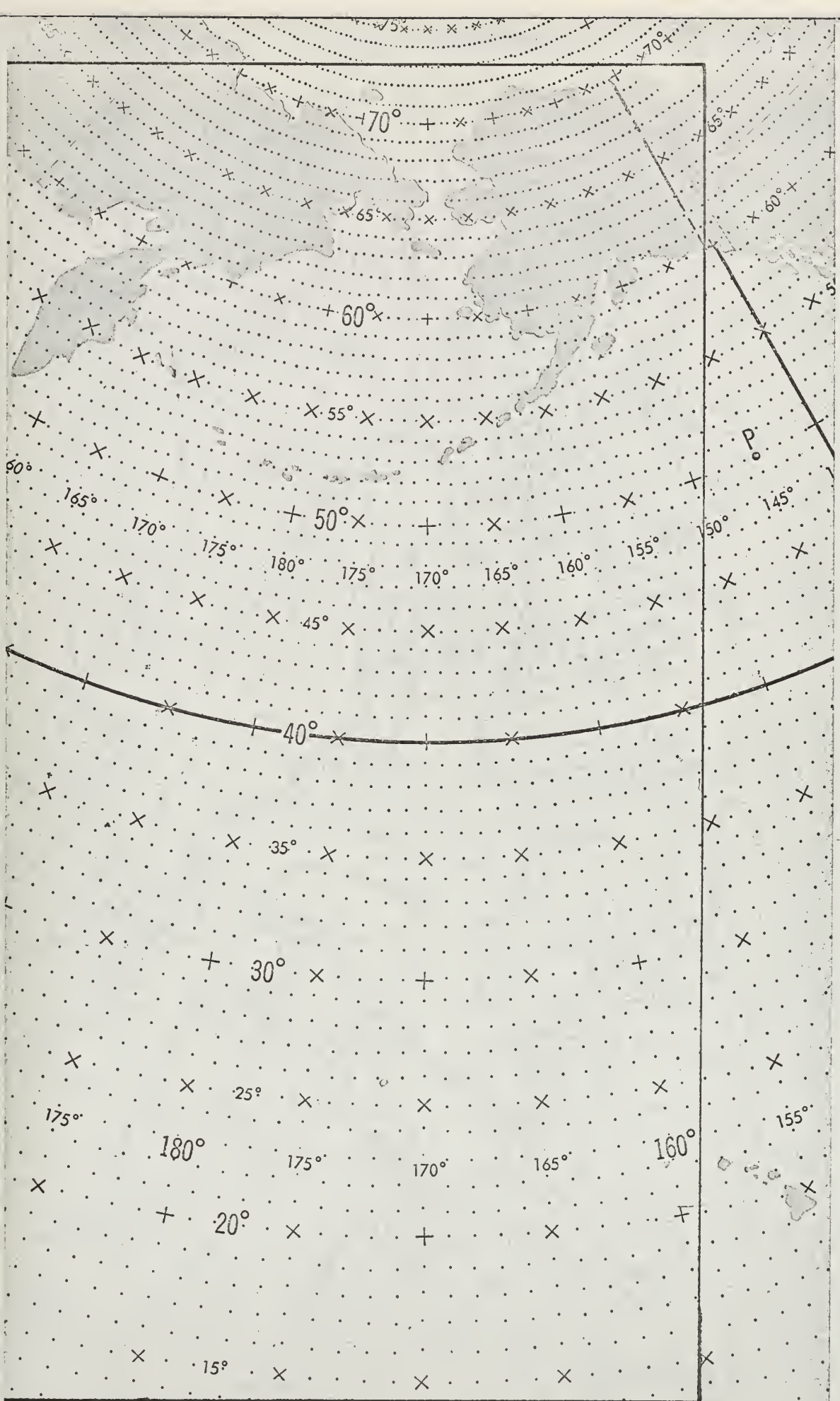
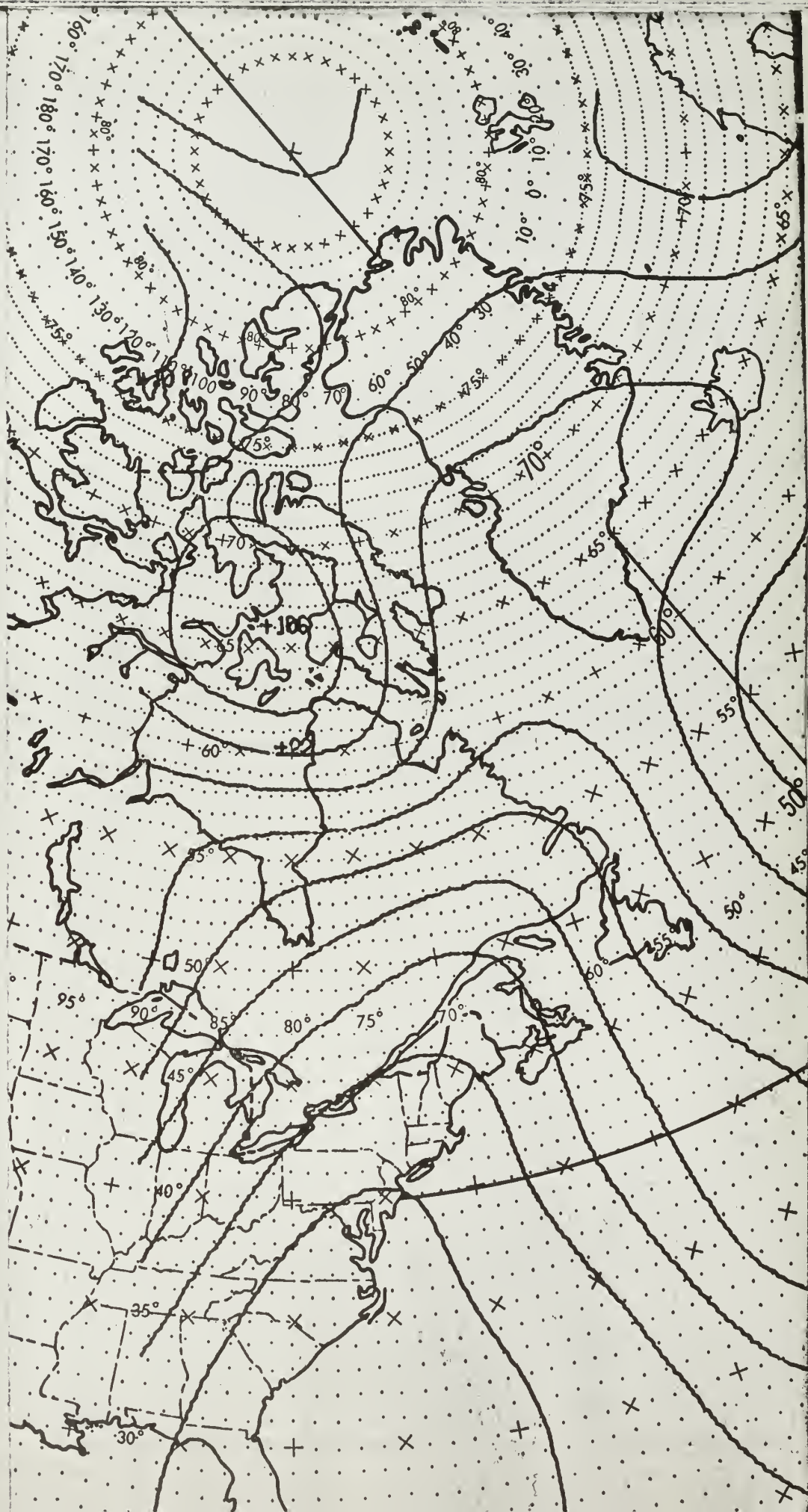


Figure 2 Area of Investigation, Pacific



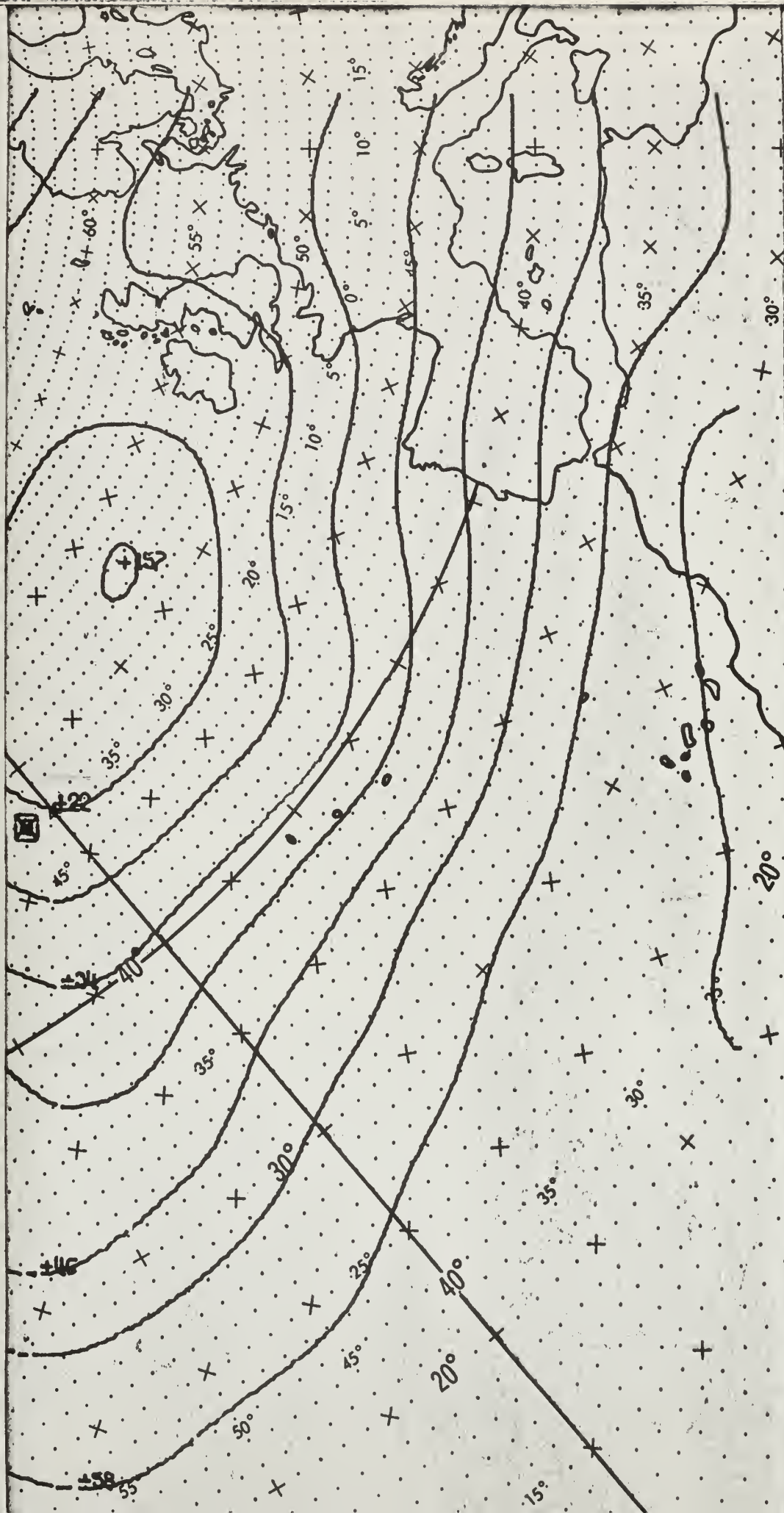
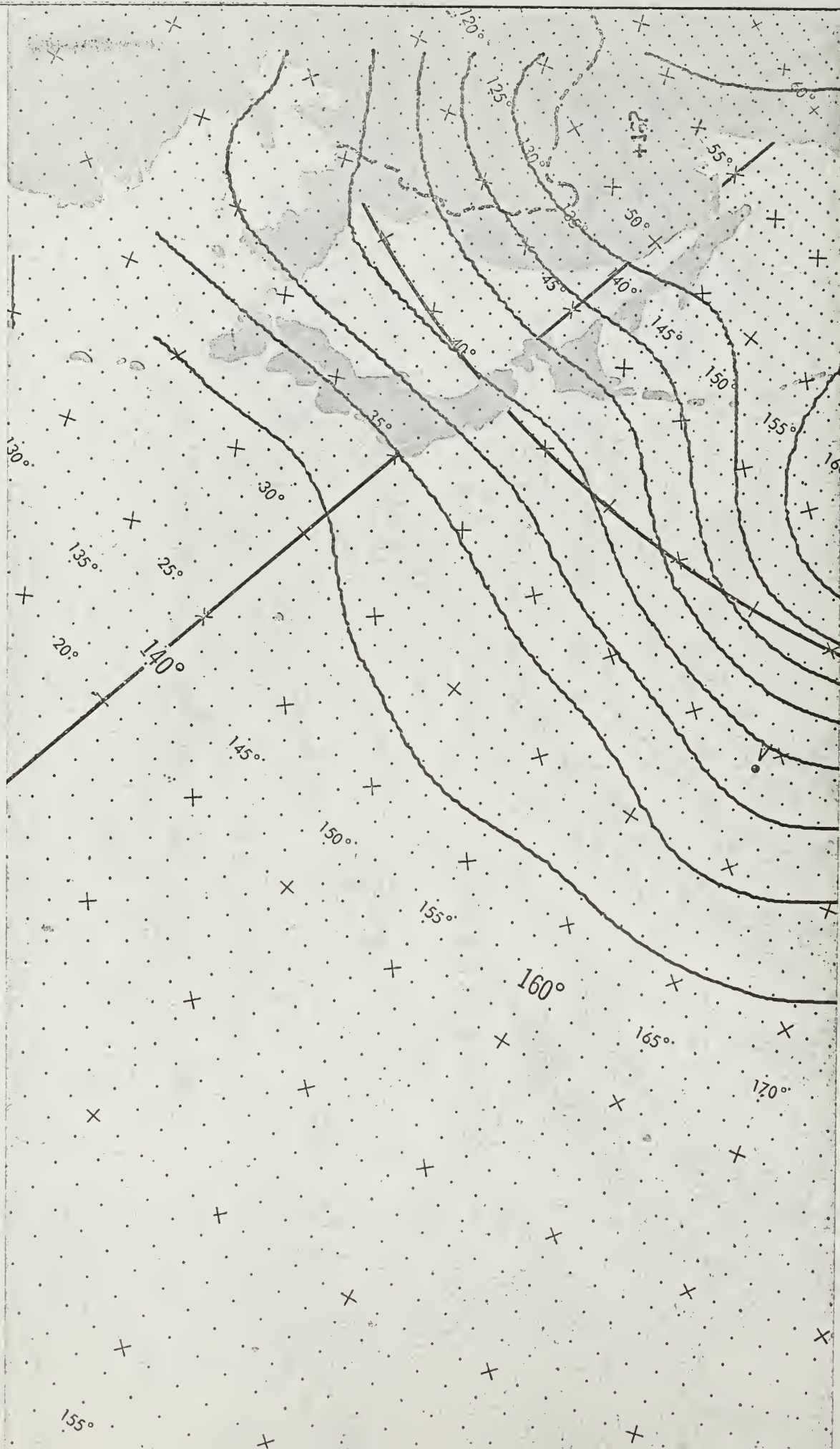


Figure 3 Stream Function Field, Ψ , Atlantic



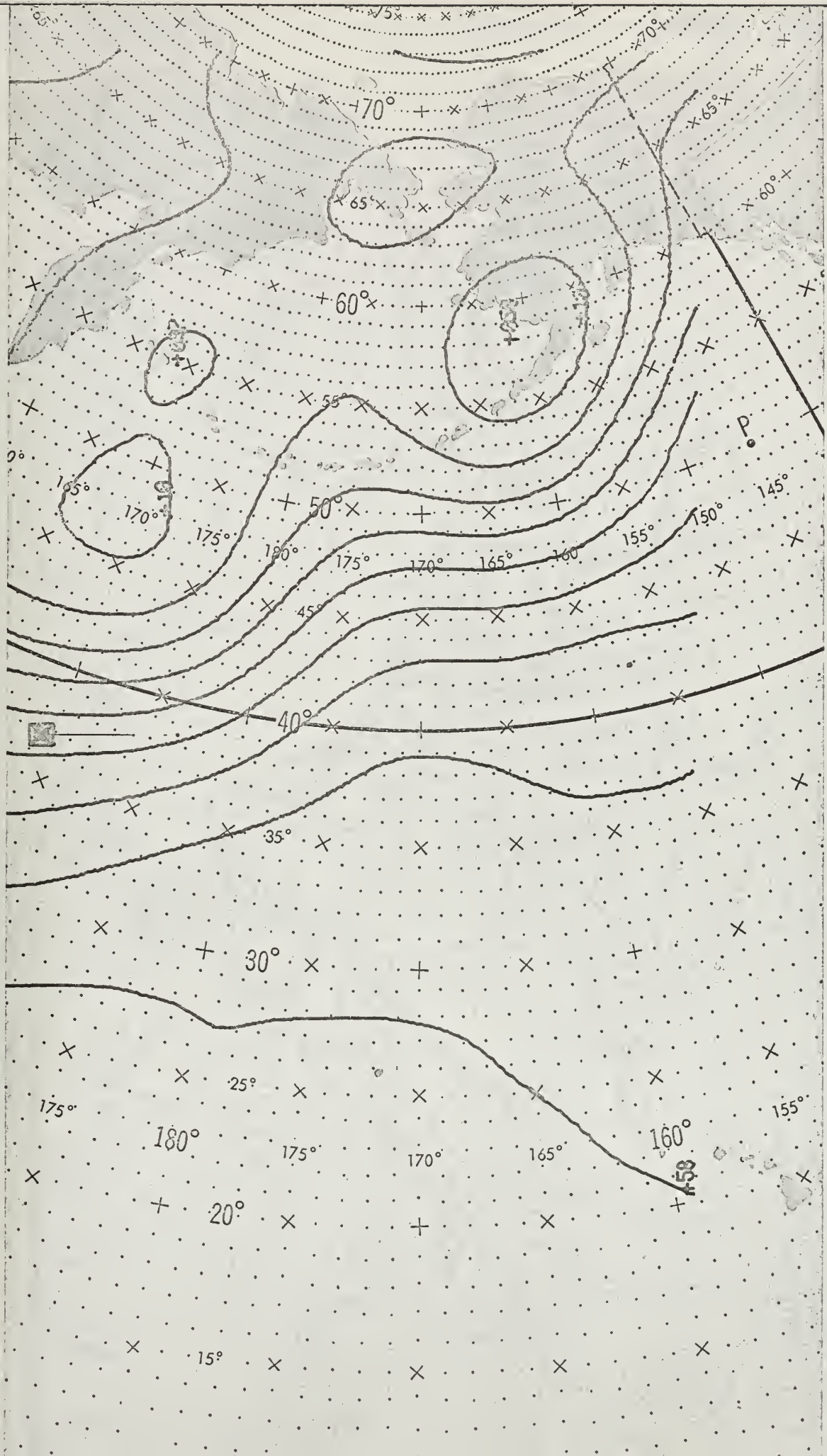
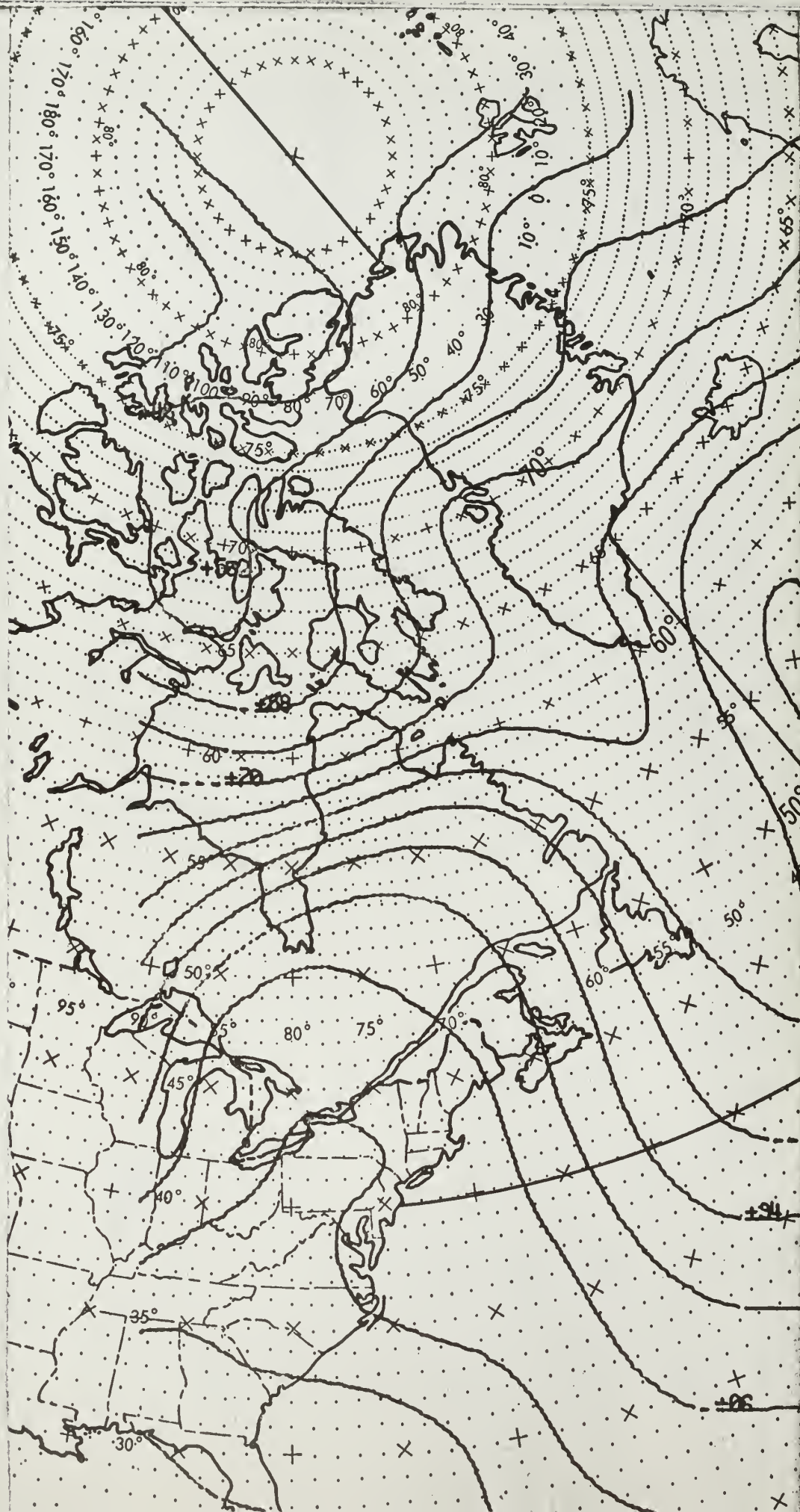


Figure 4 Stream Function Field, ψ , Pacific



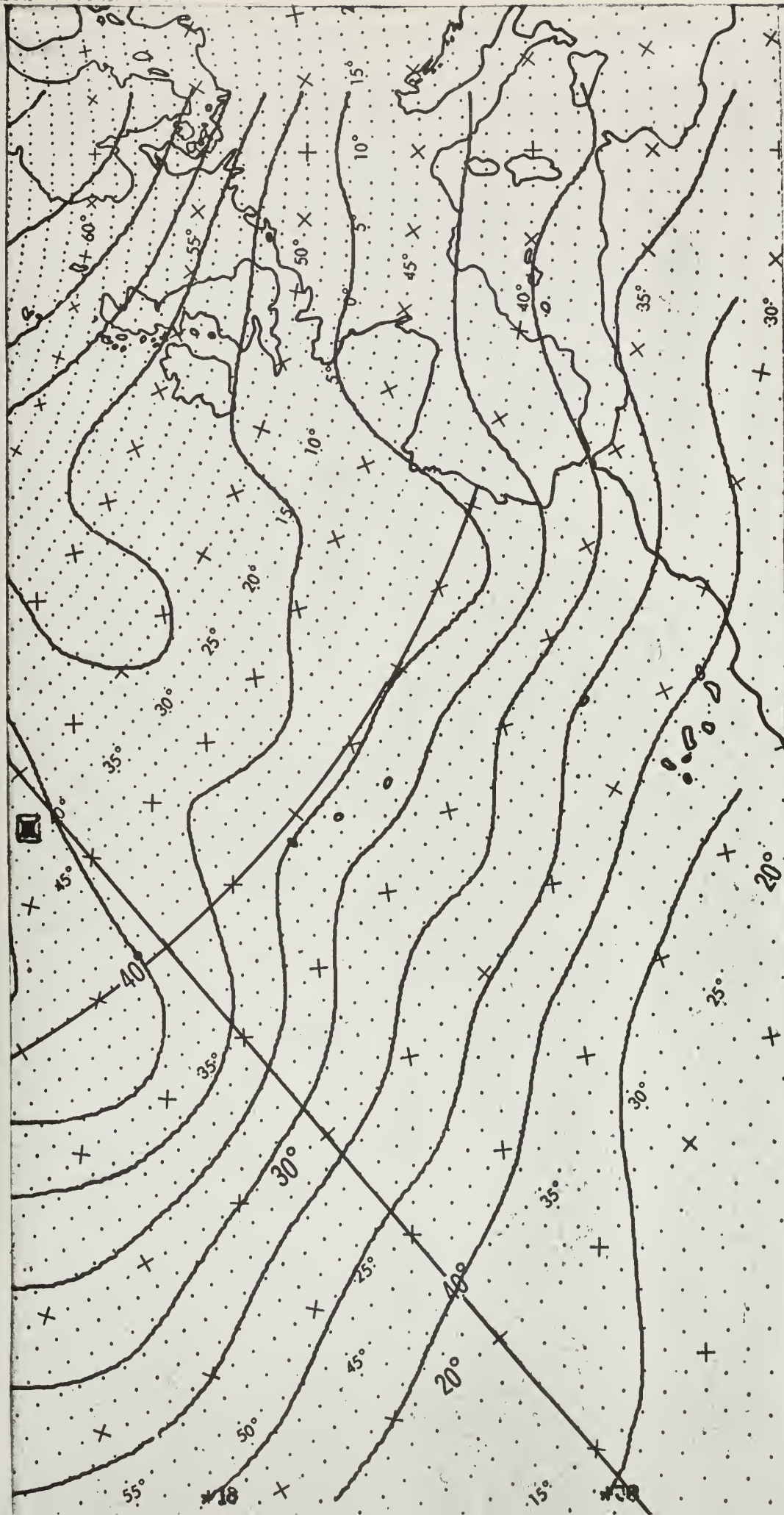


Figure 5 1000 - 500 mb thickness field, h, Atlantic



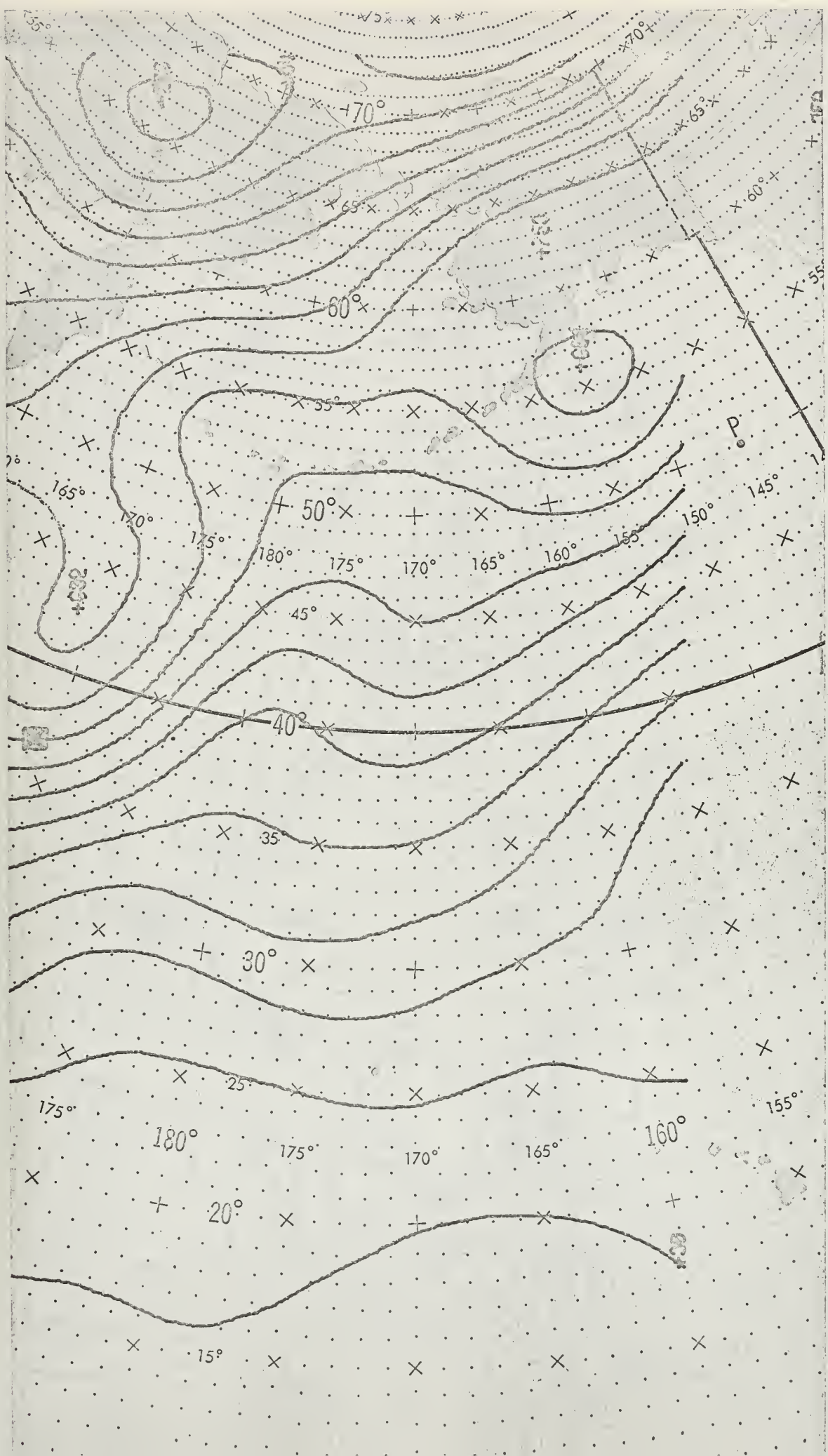
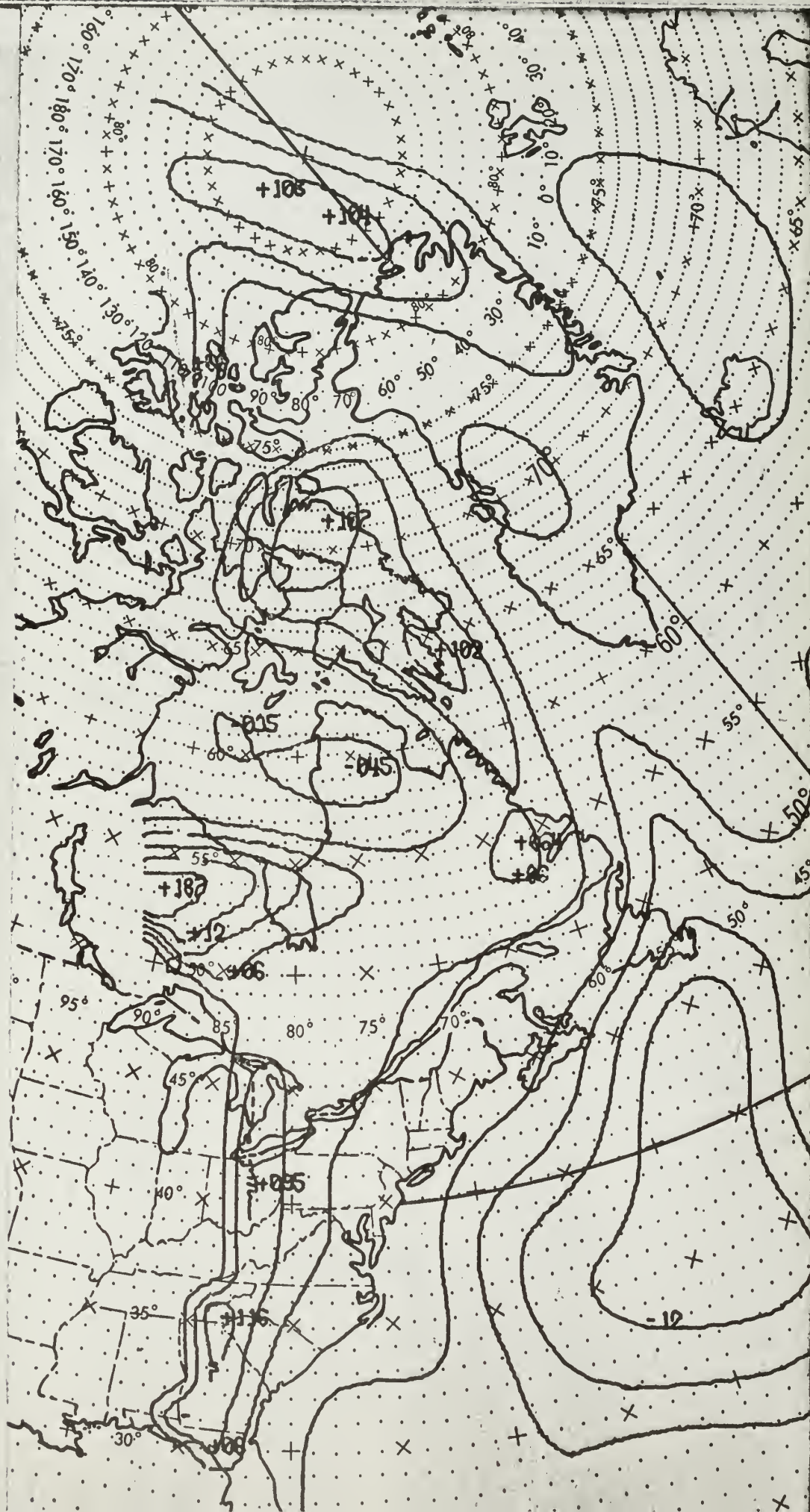


Figure 6 Thickness field, h, Pacific



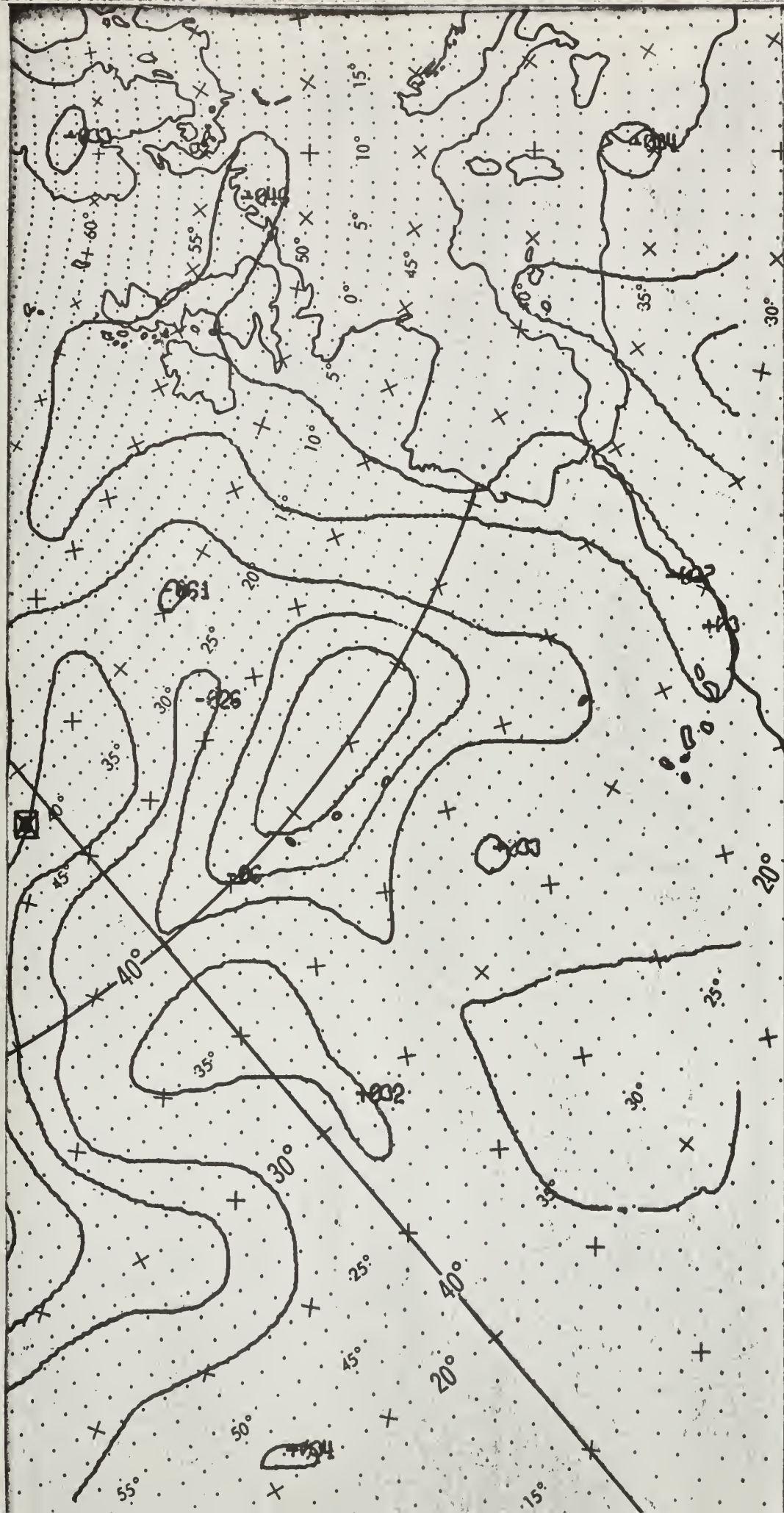


Figure 7 shows the combined local change of thickness and estimated horizontal advection, Atlantic



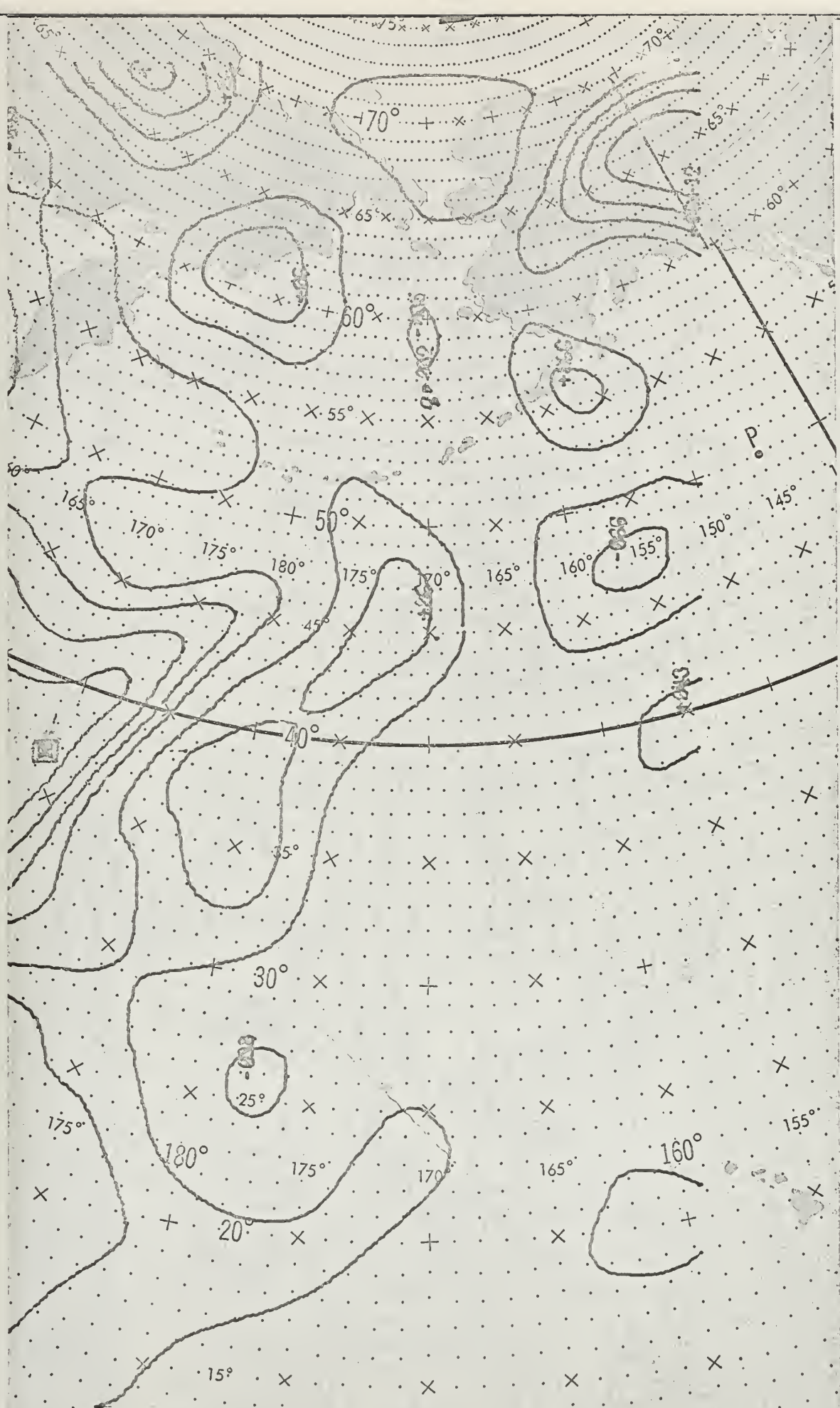
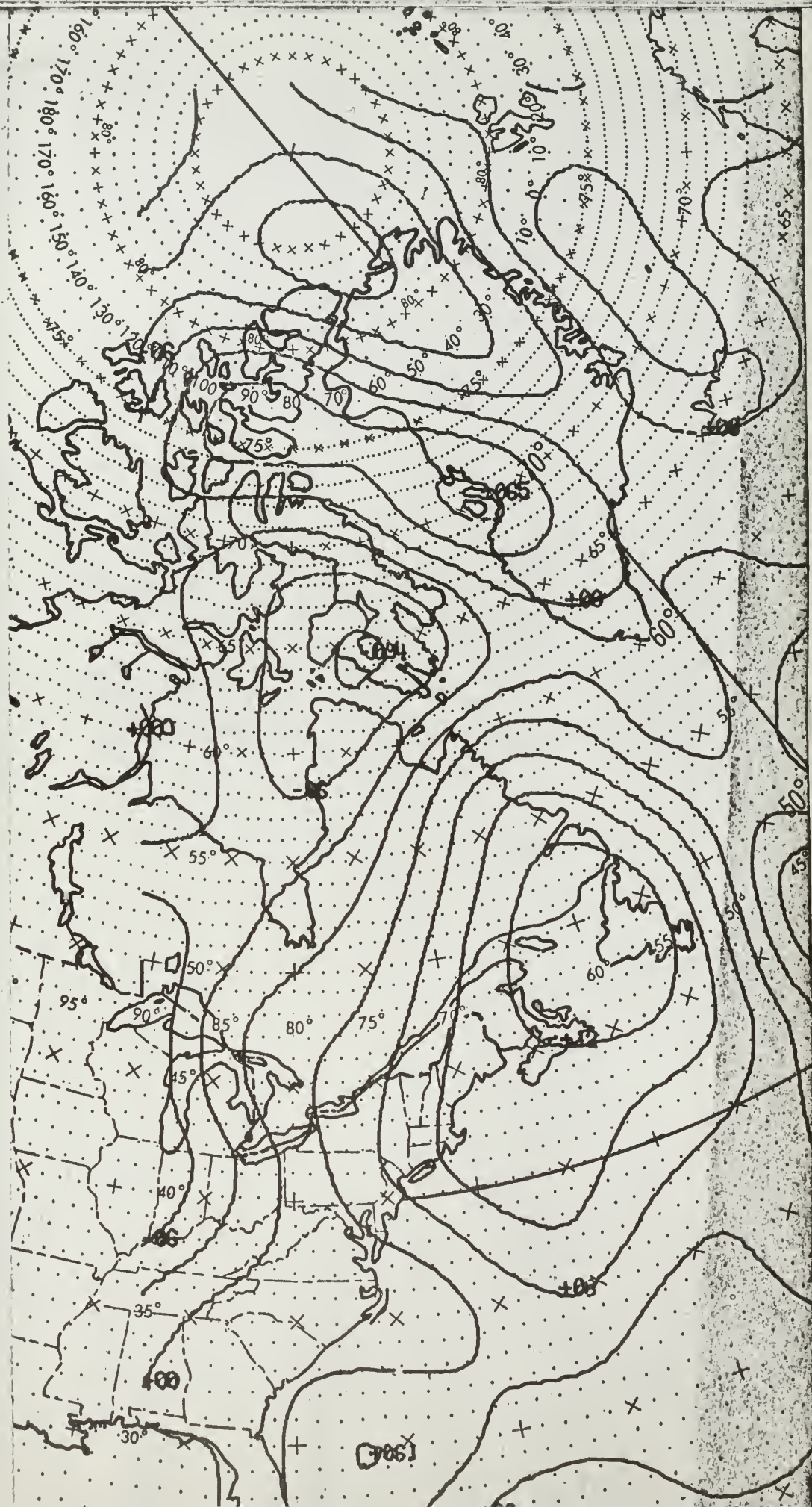


Figure 8 h ; the combined local change of thickness and estimated horizontal advection, Pacific



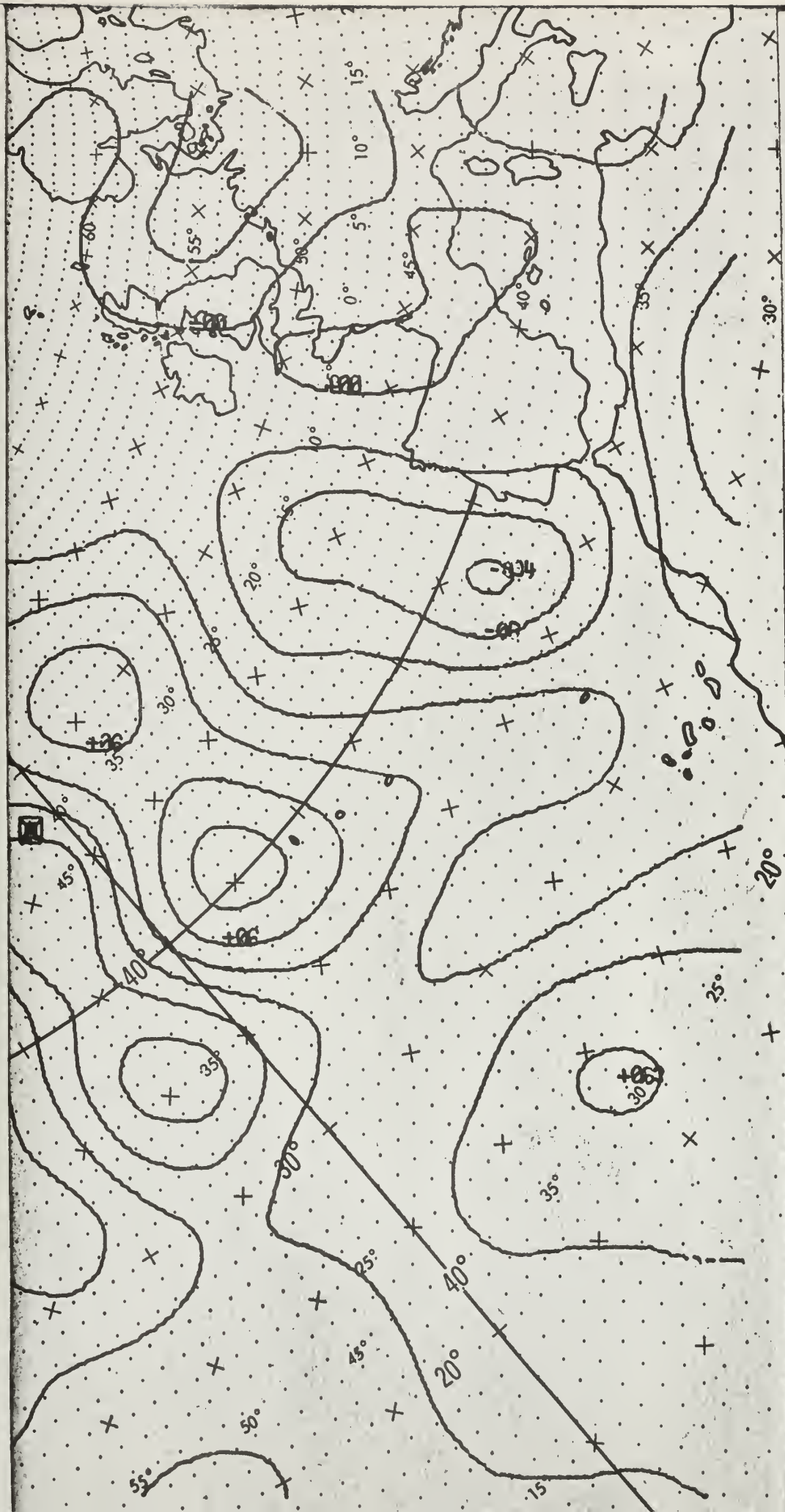
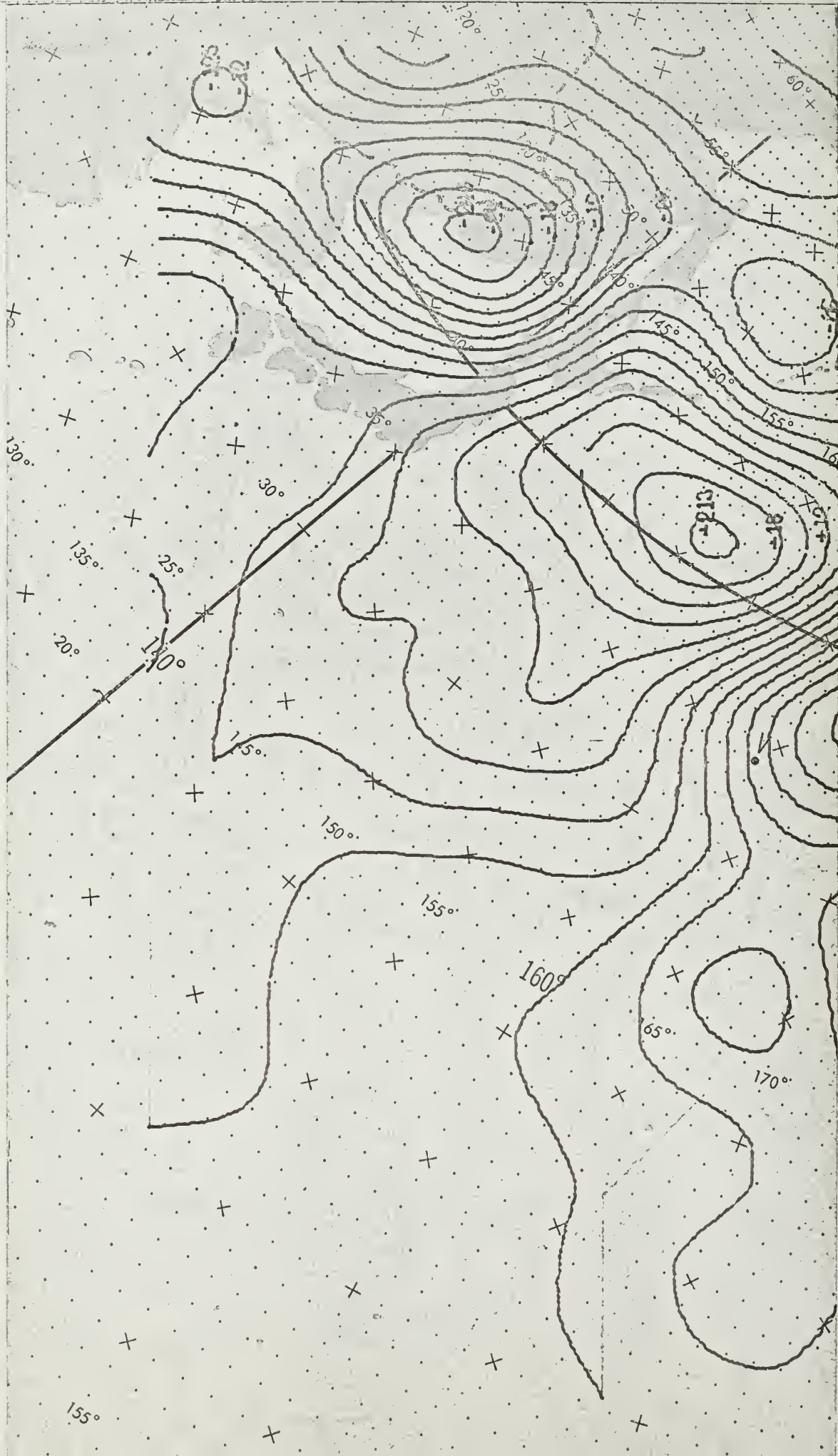


Figure 9 Local change of thickness, Δh , Atlantic



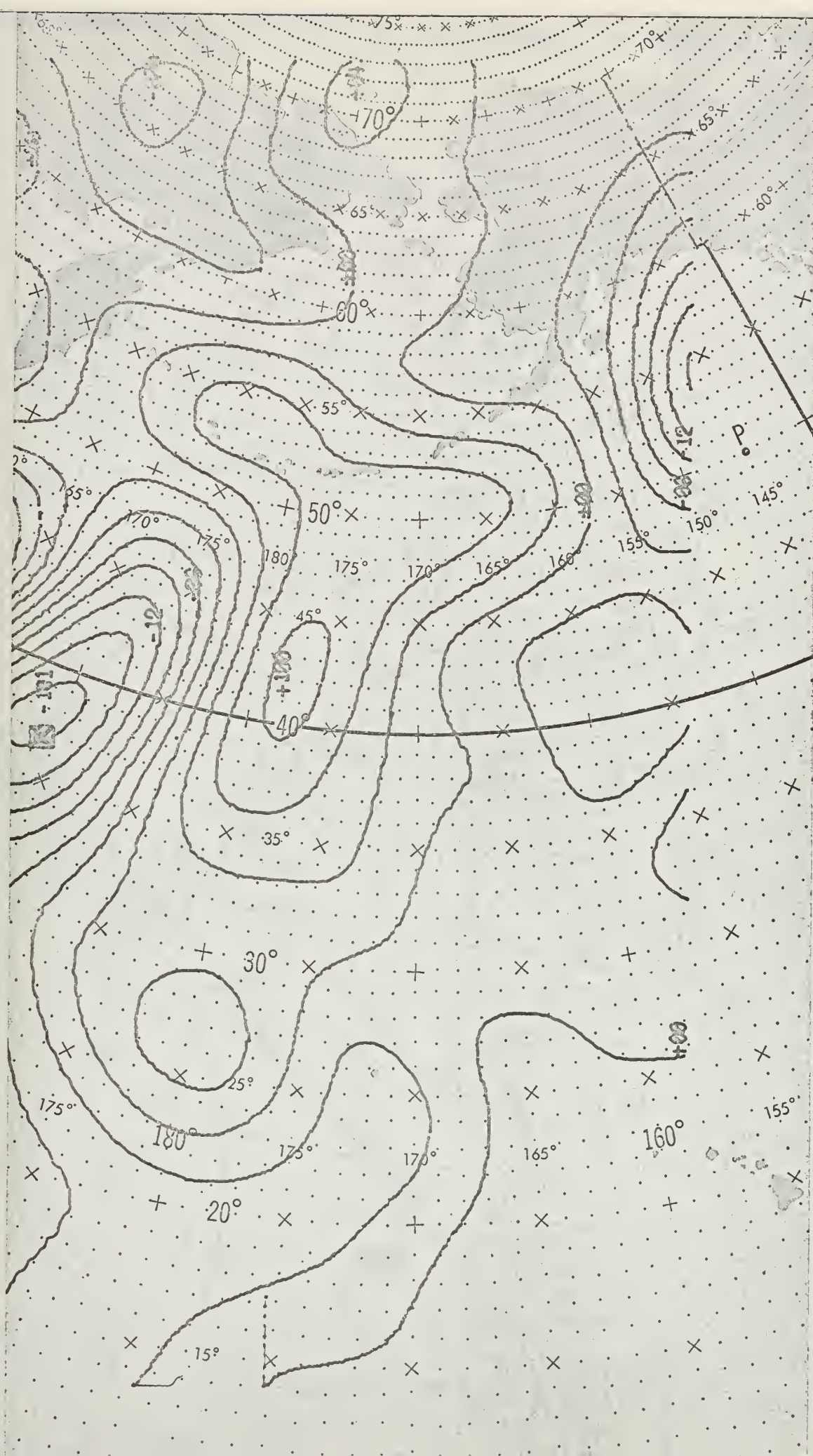
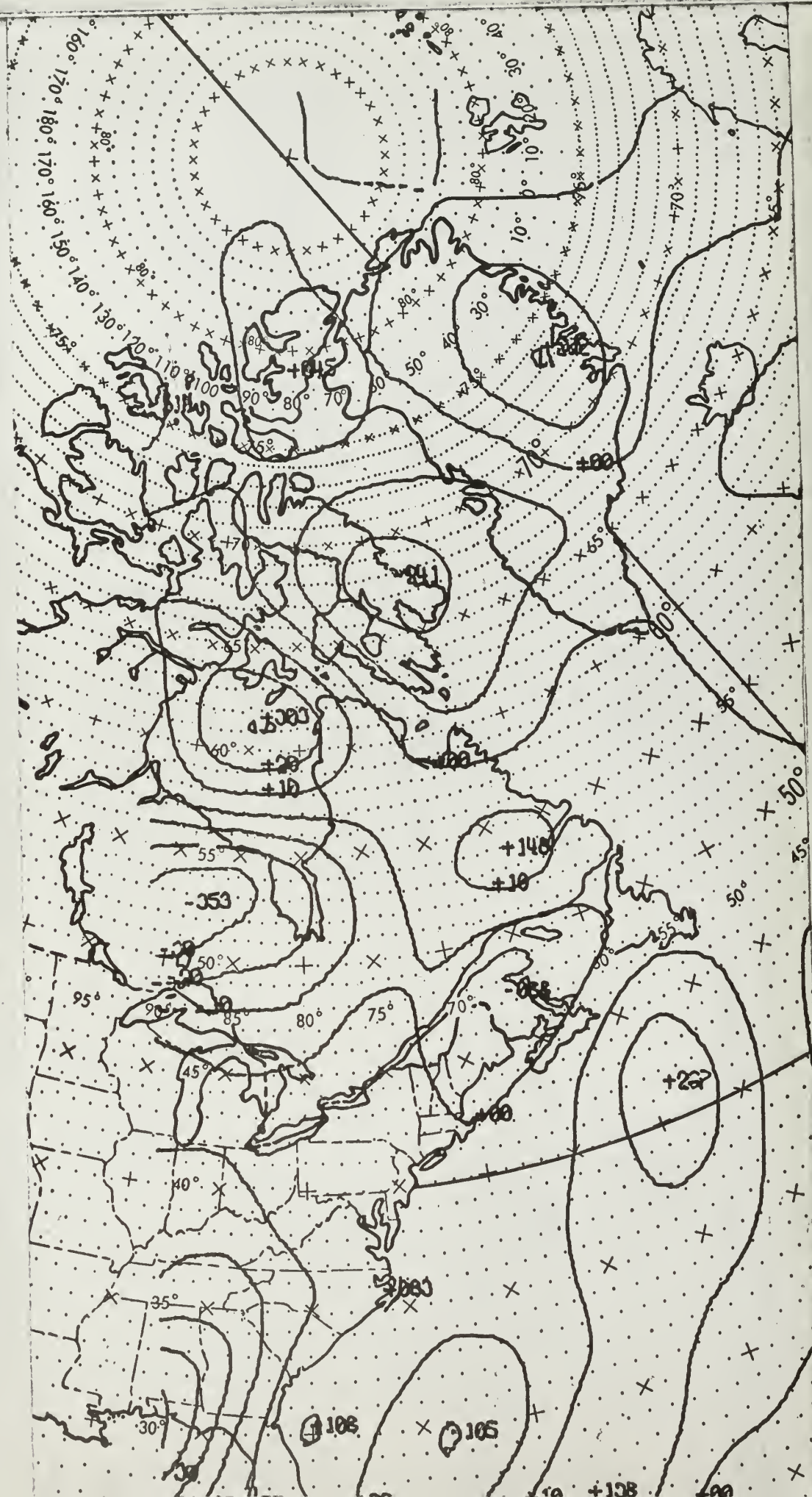


Figure 10 Local change of thickness, Δh , Pacific



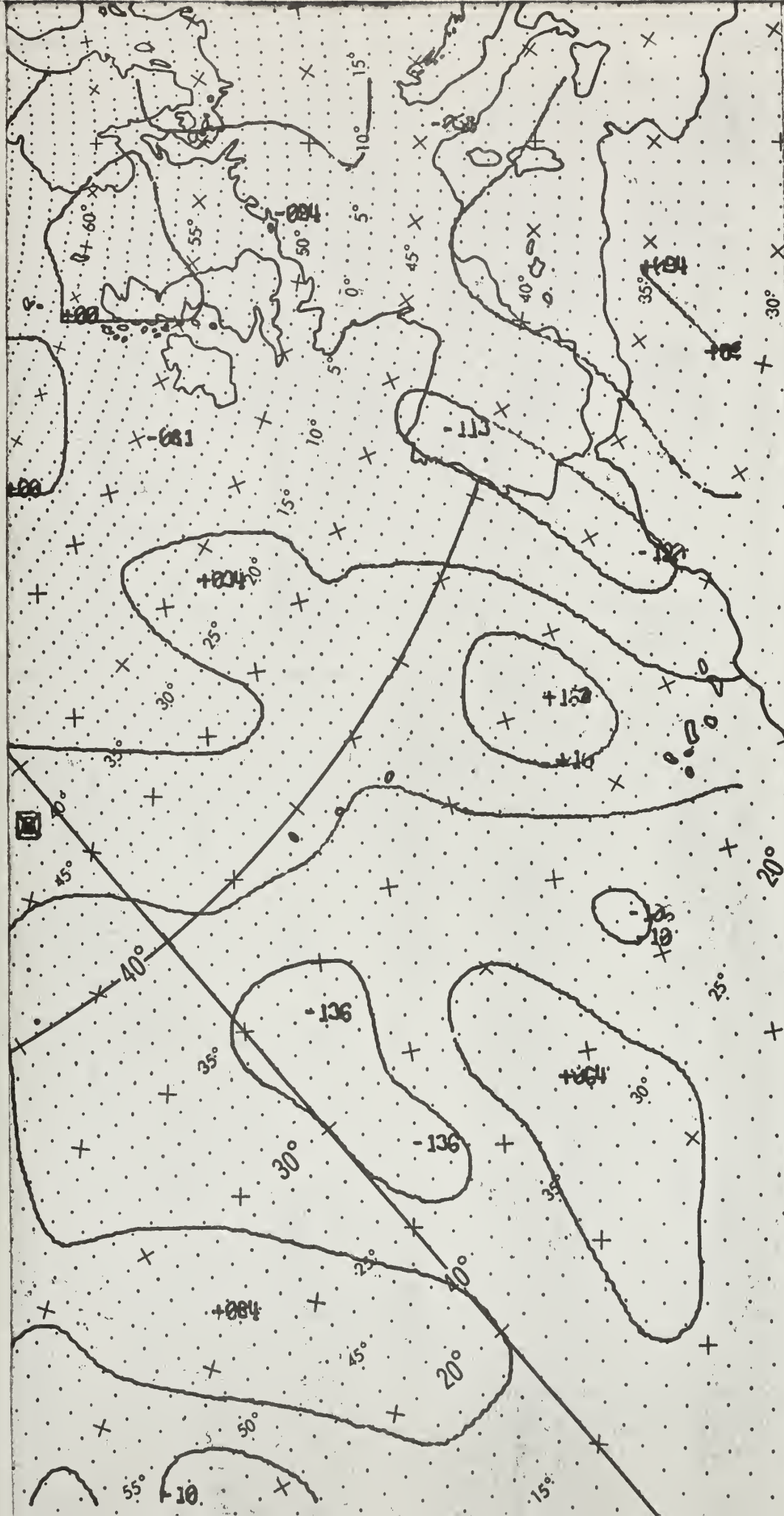
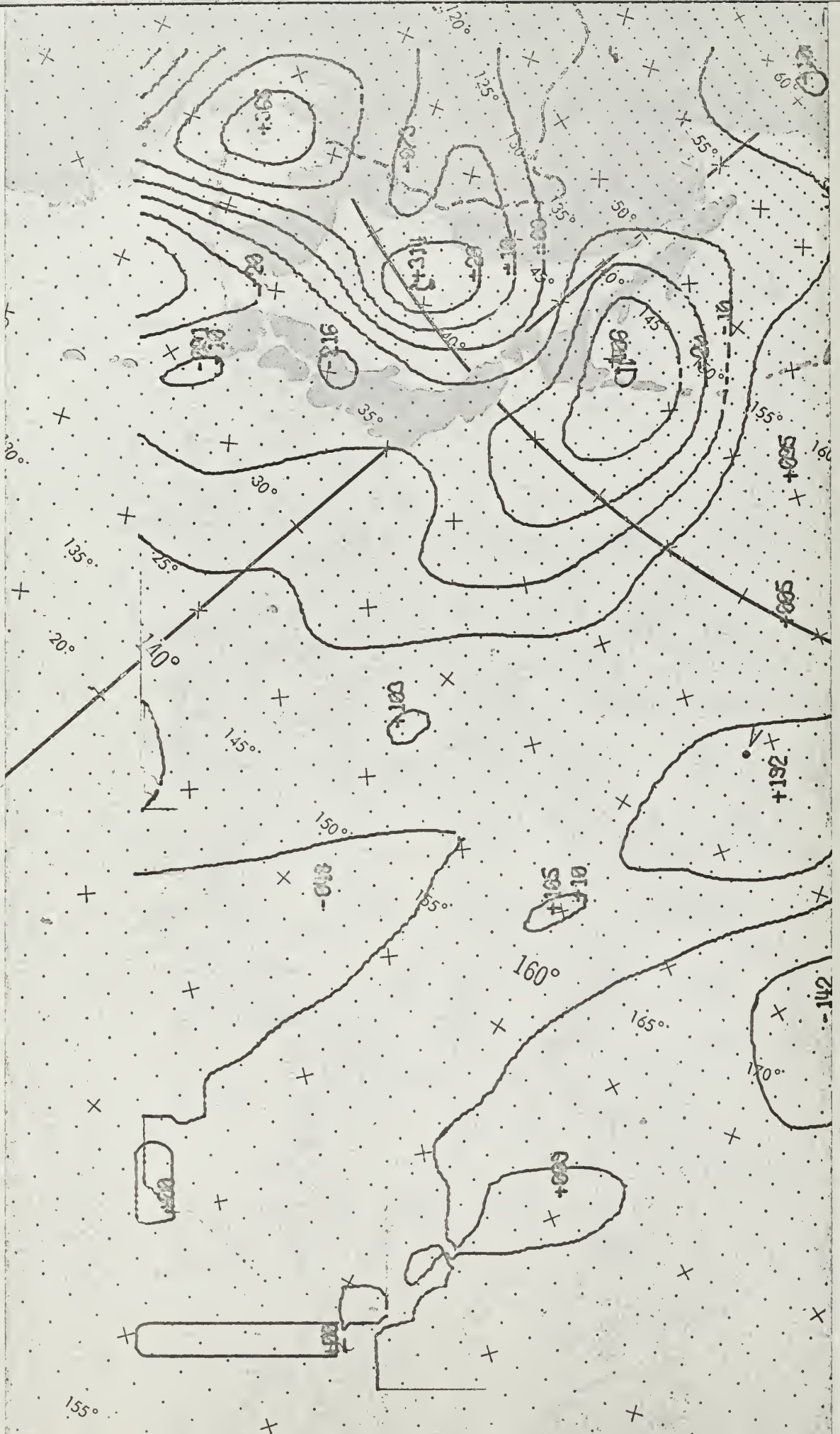


Figure 11 σ_T 850, Atlantic



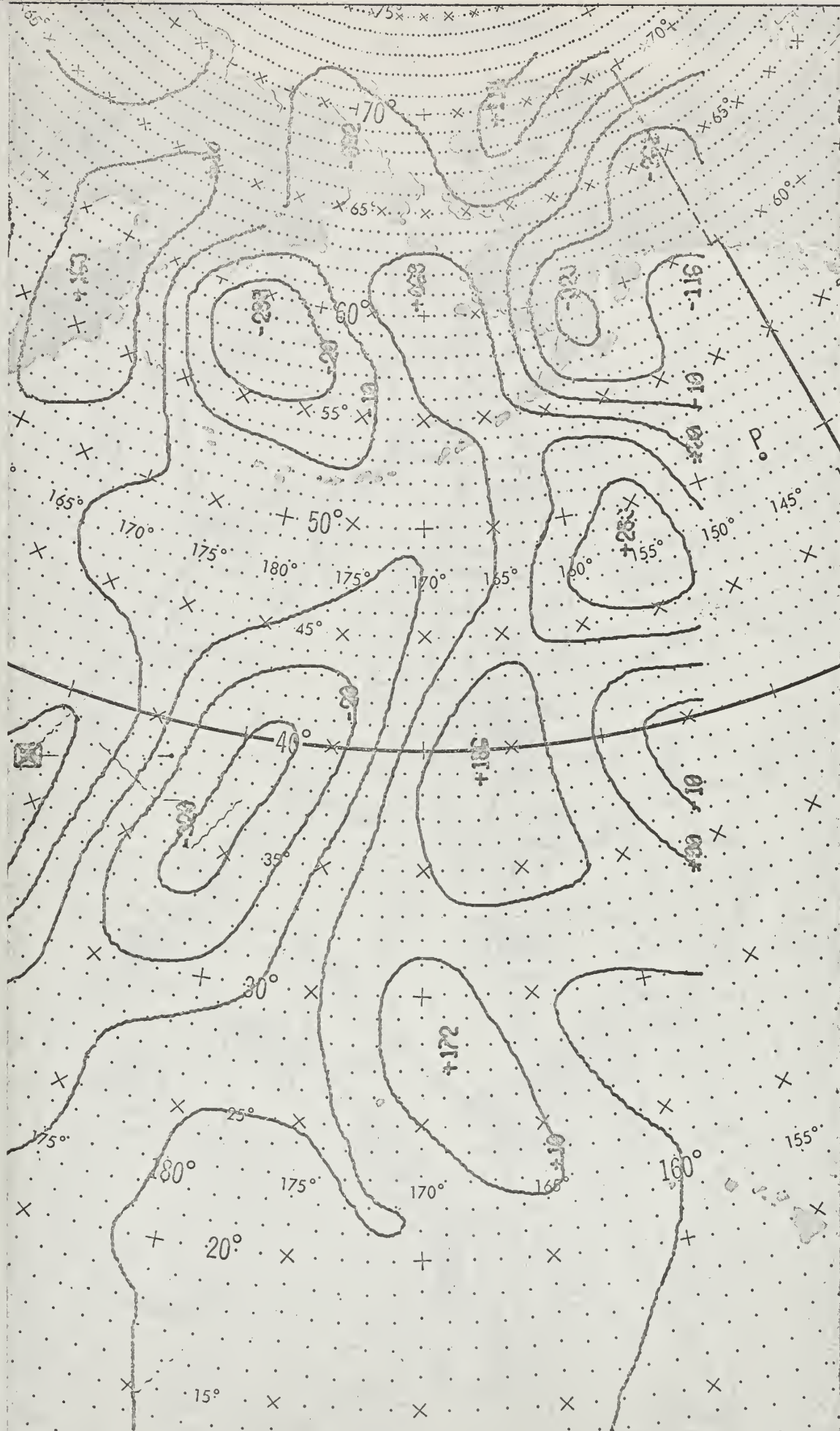


Figure 12 σ_w 850' Pacific

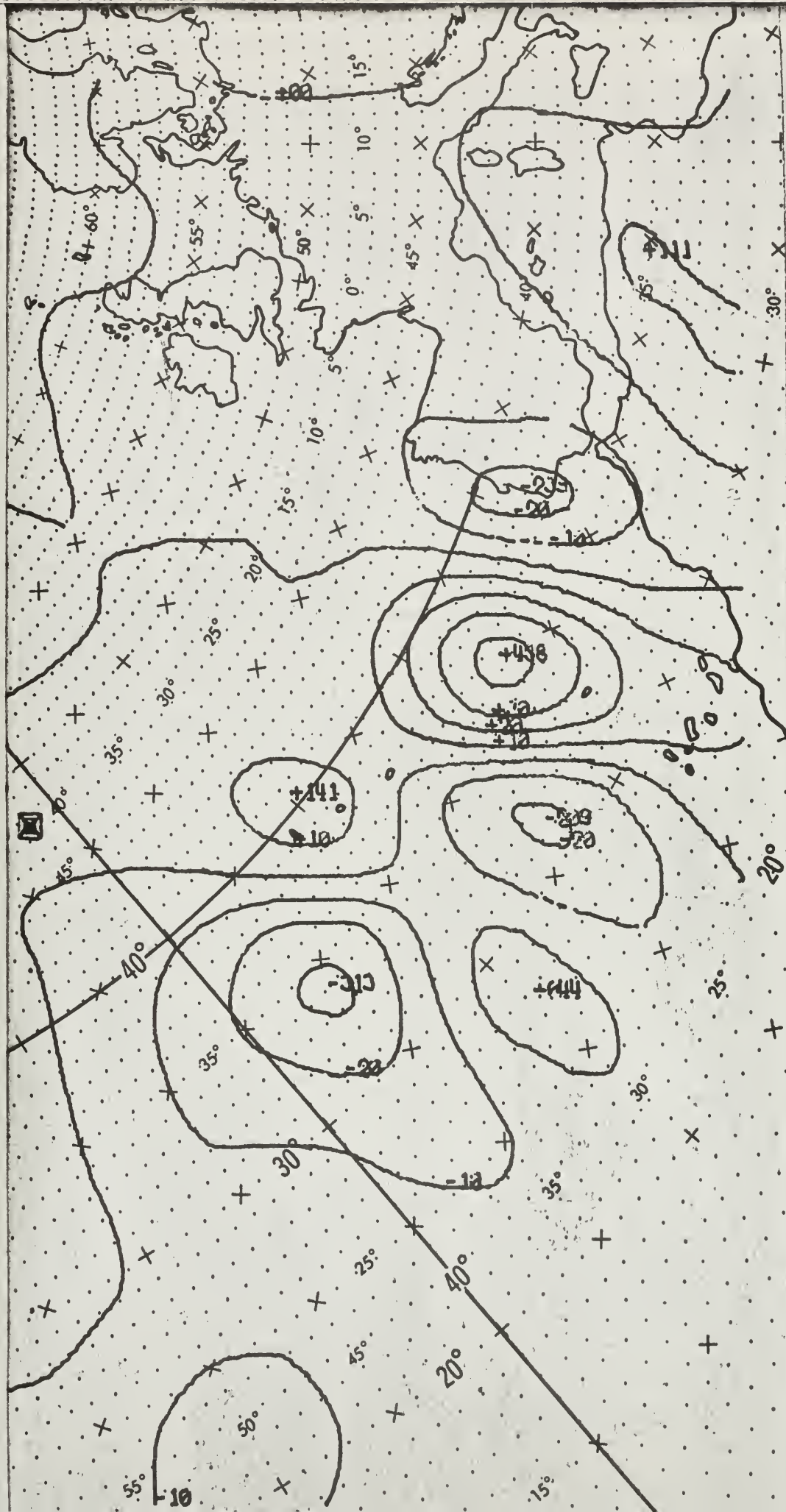
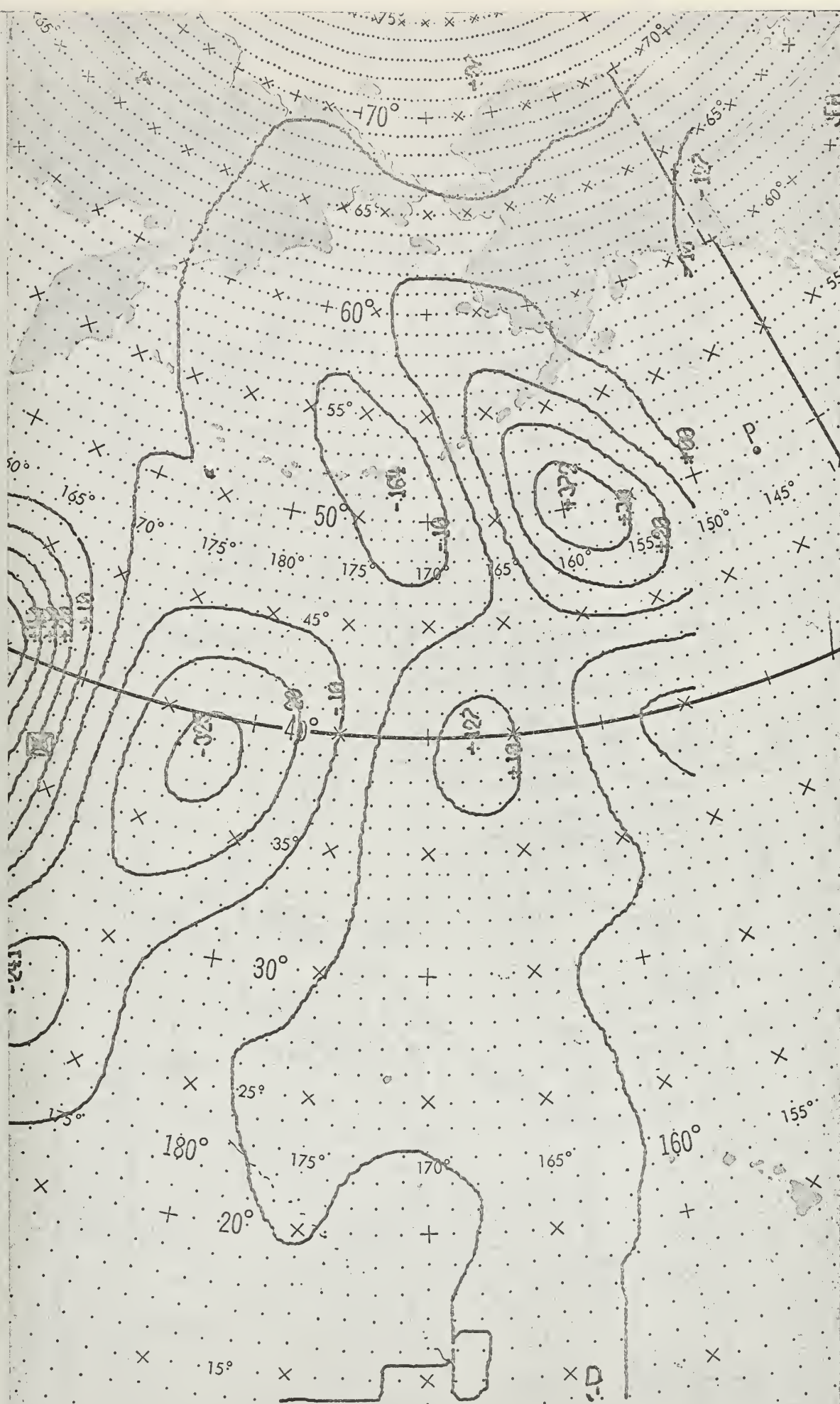
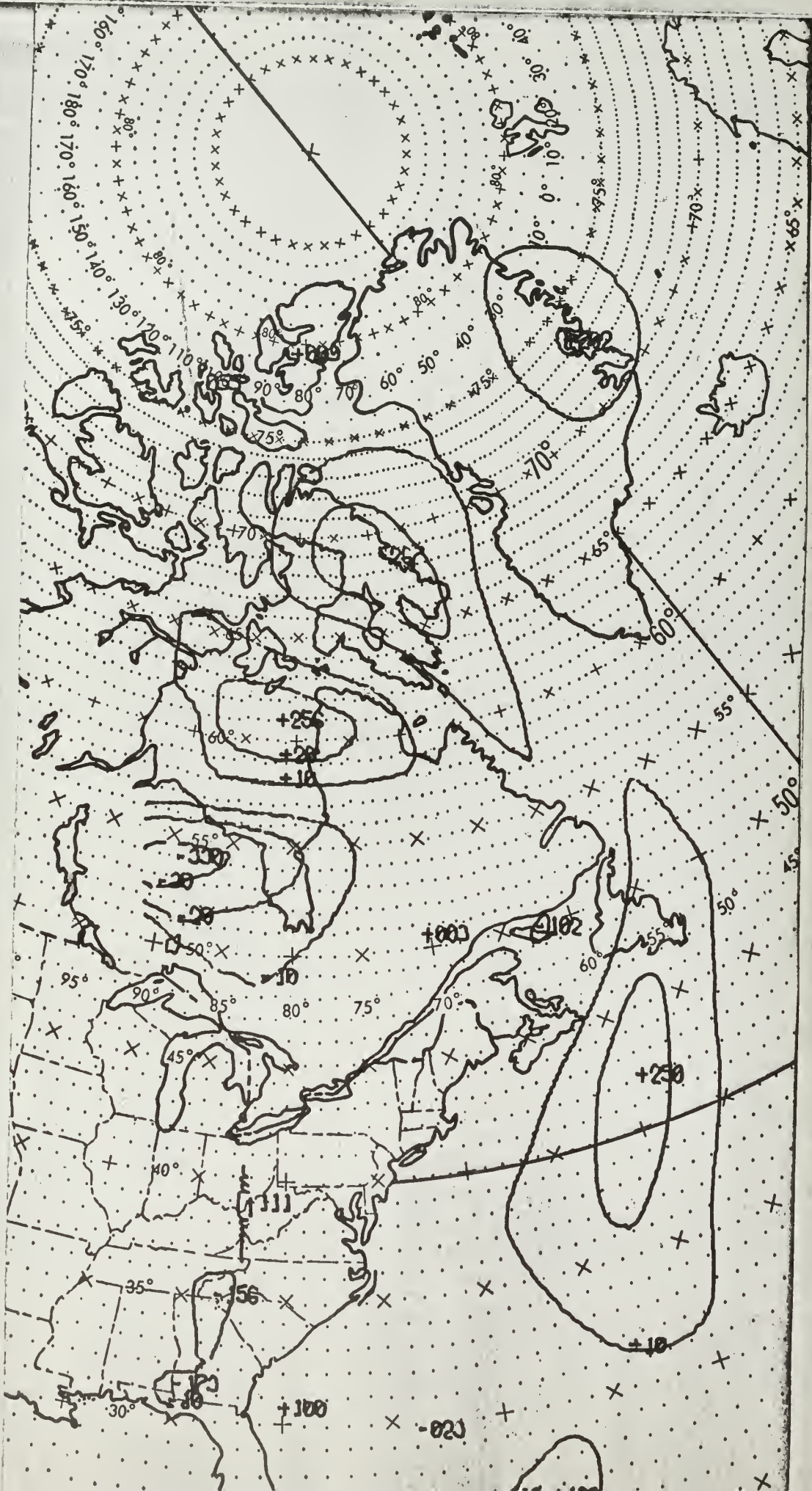
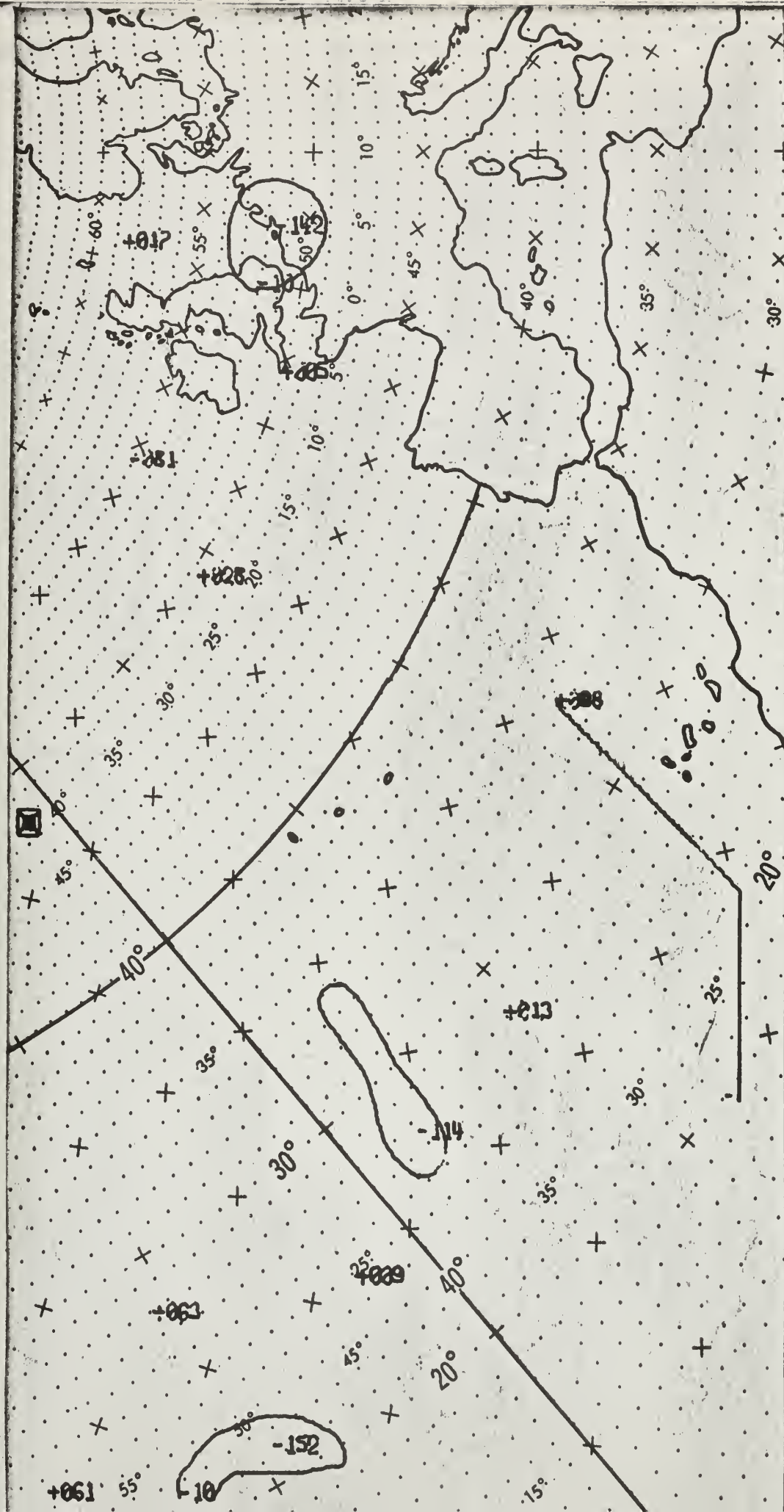


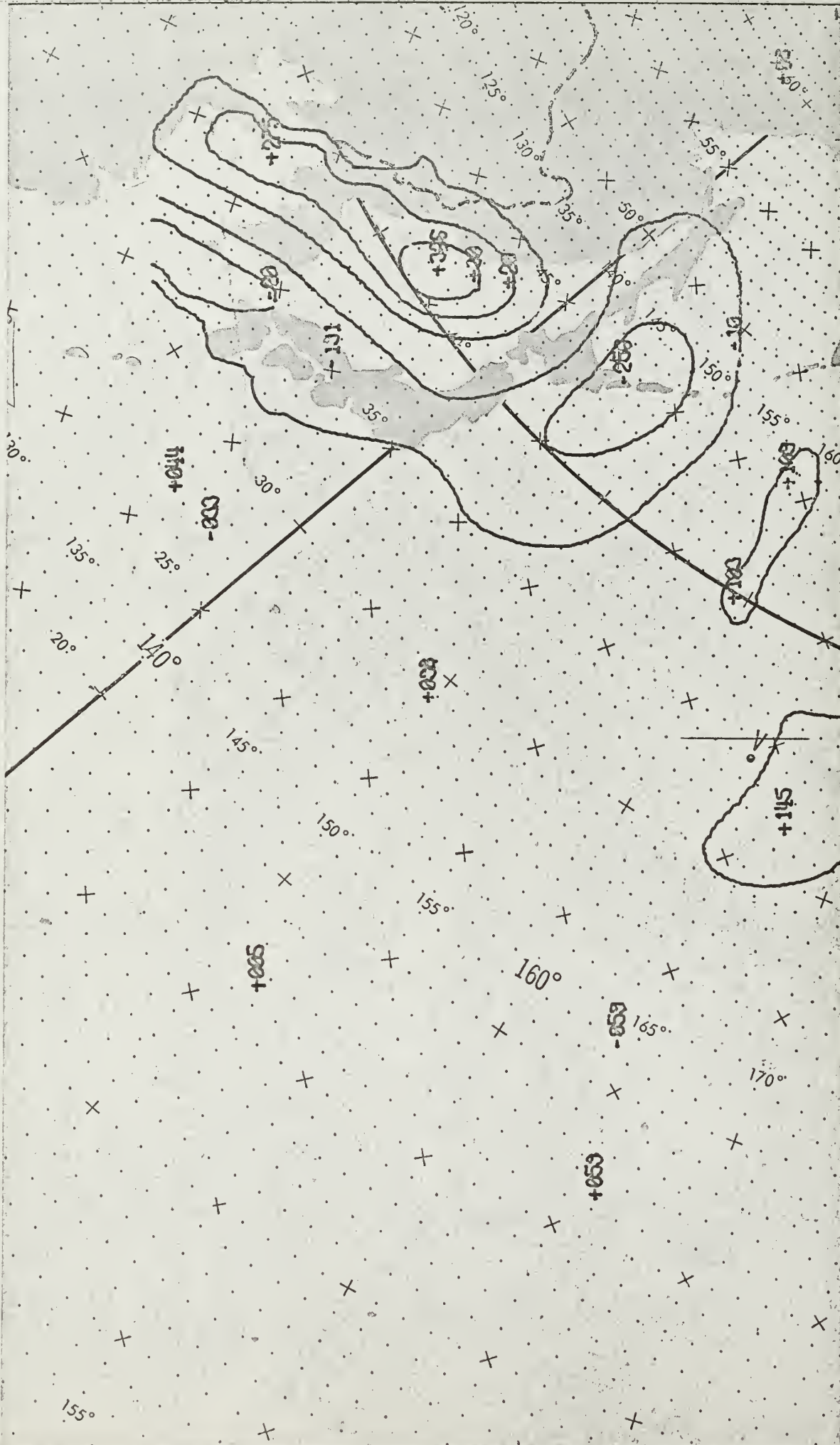
Figure 13 σ_{500} , Atlantic











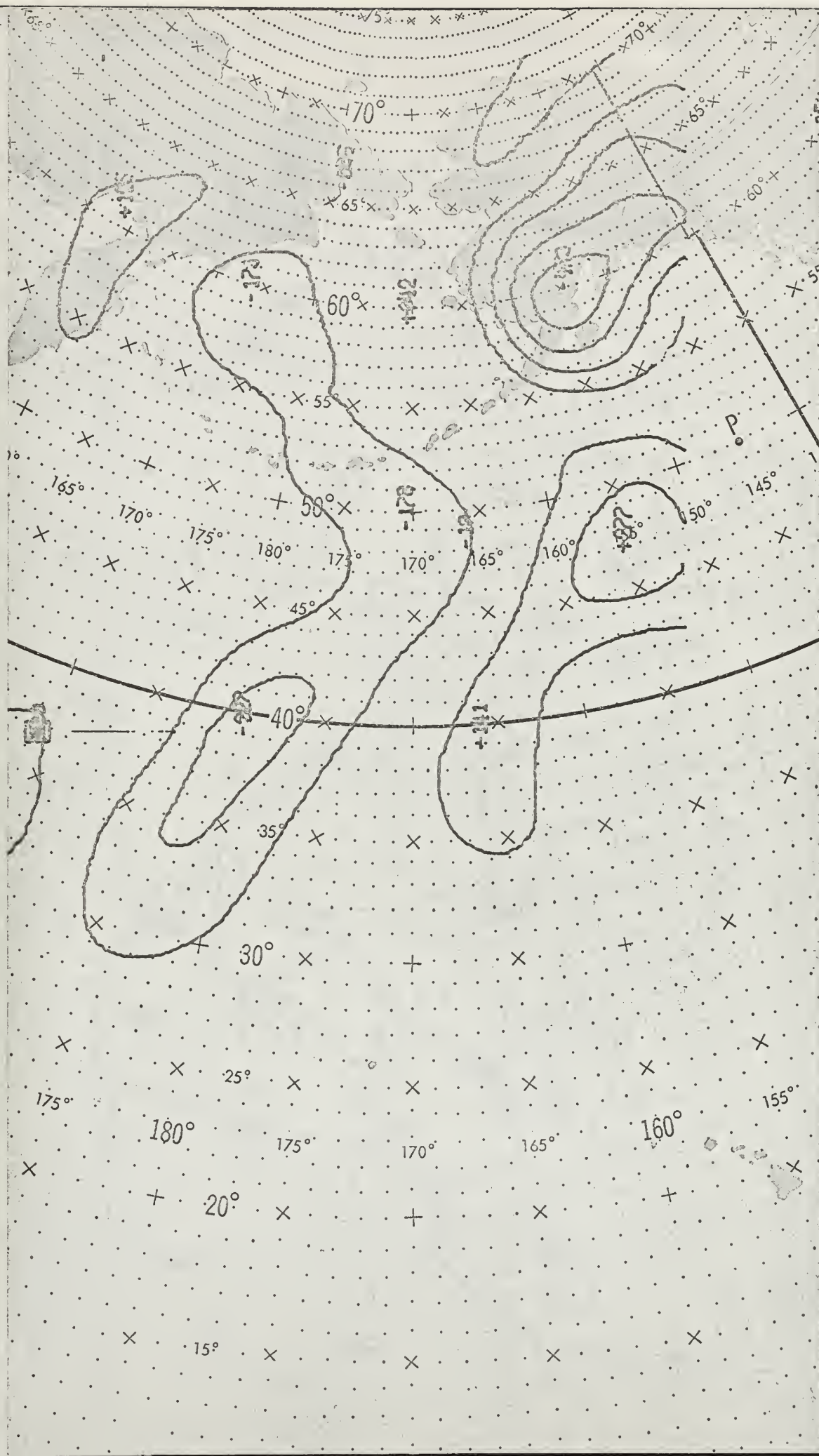
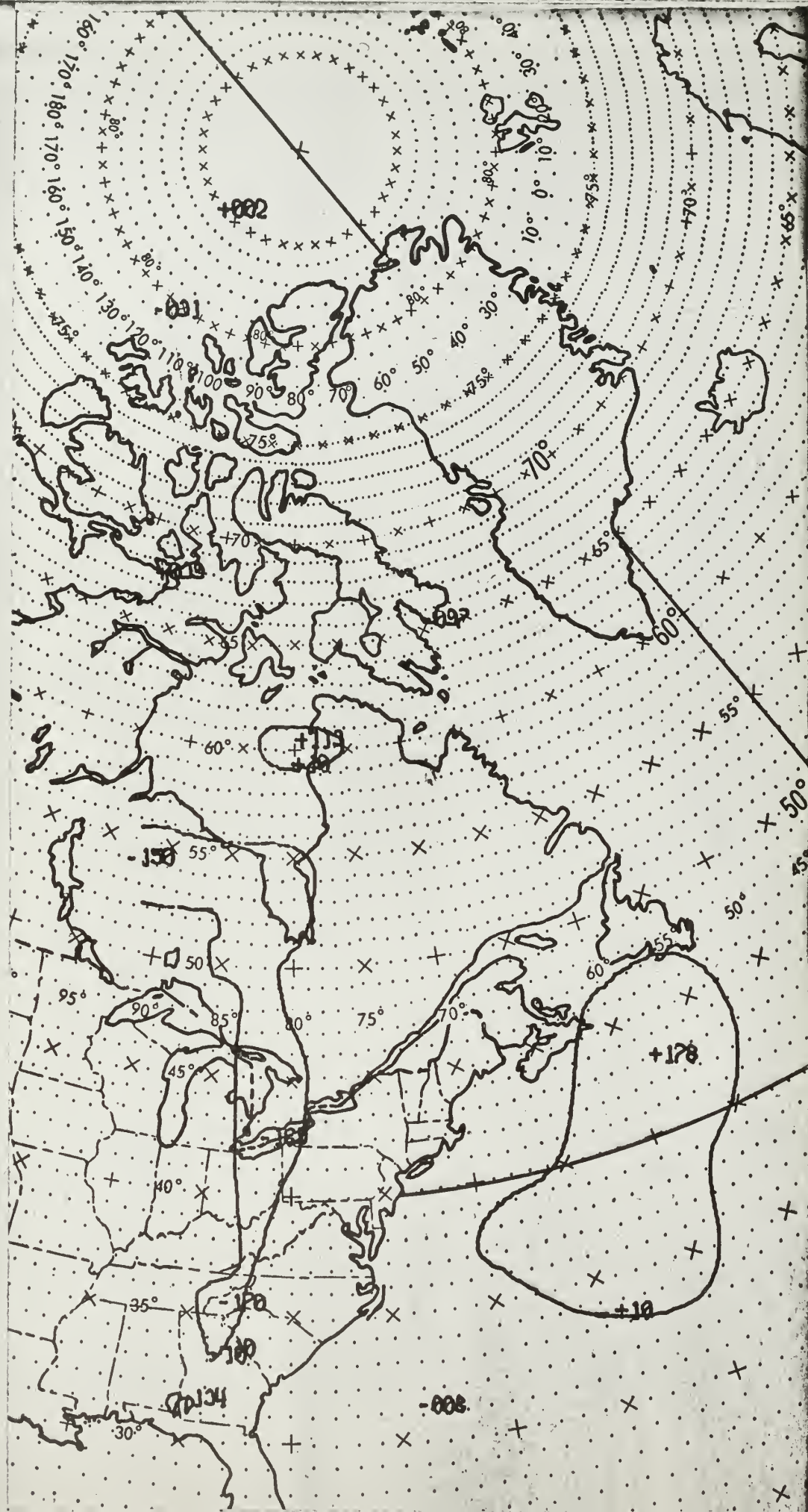


Figure 16 σ_t 850' Pacific



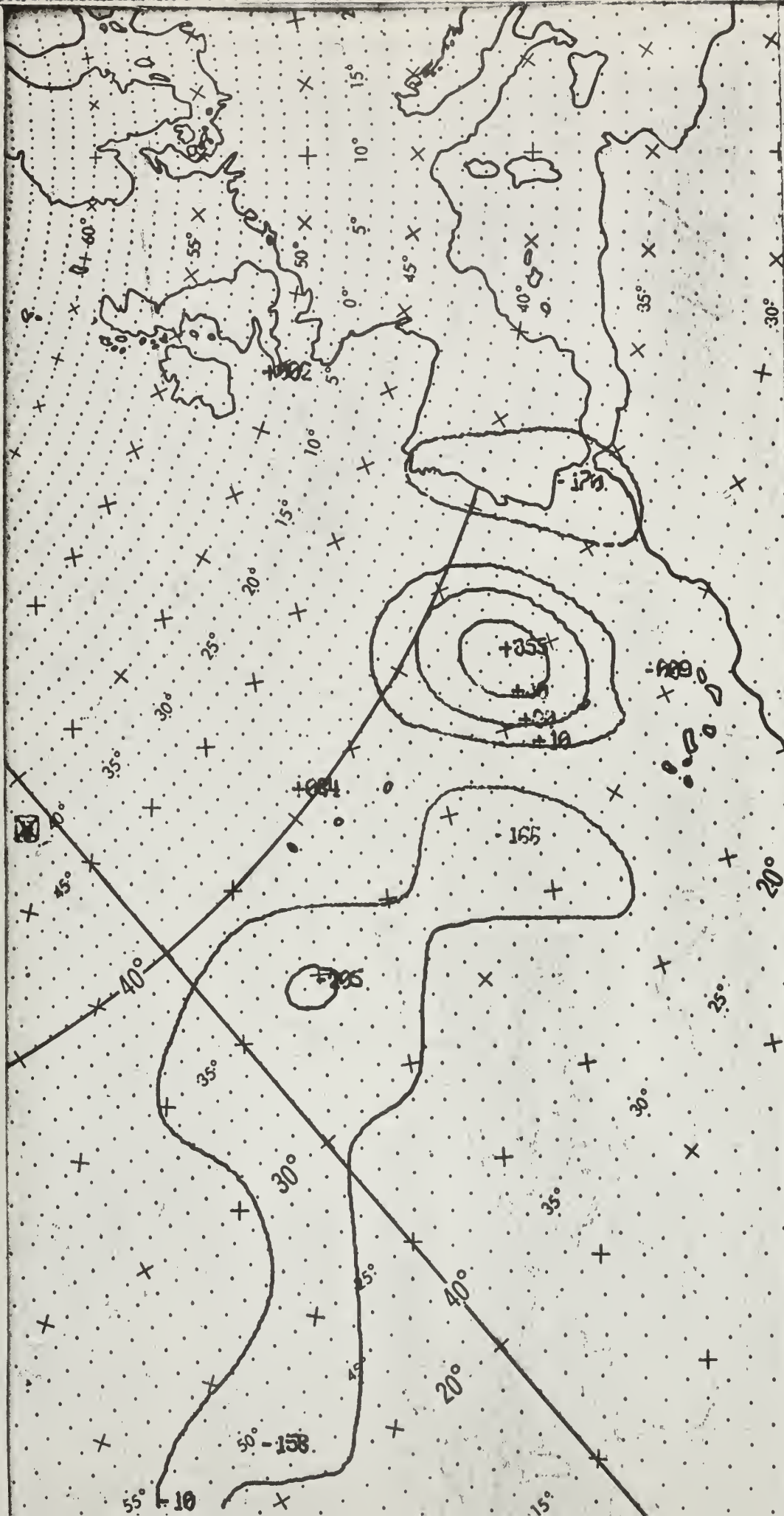


Figure 17 $\overline{\sigma\omega}$ 500, Atlantic



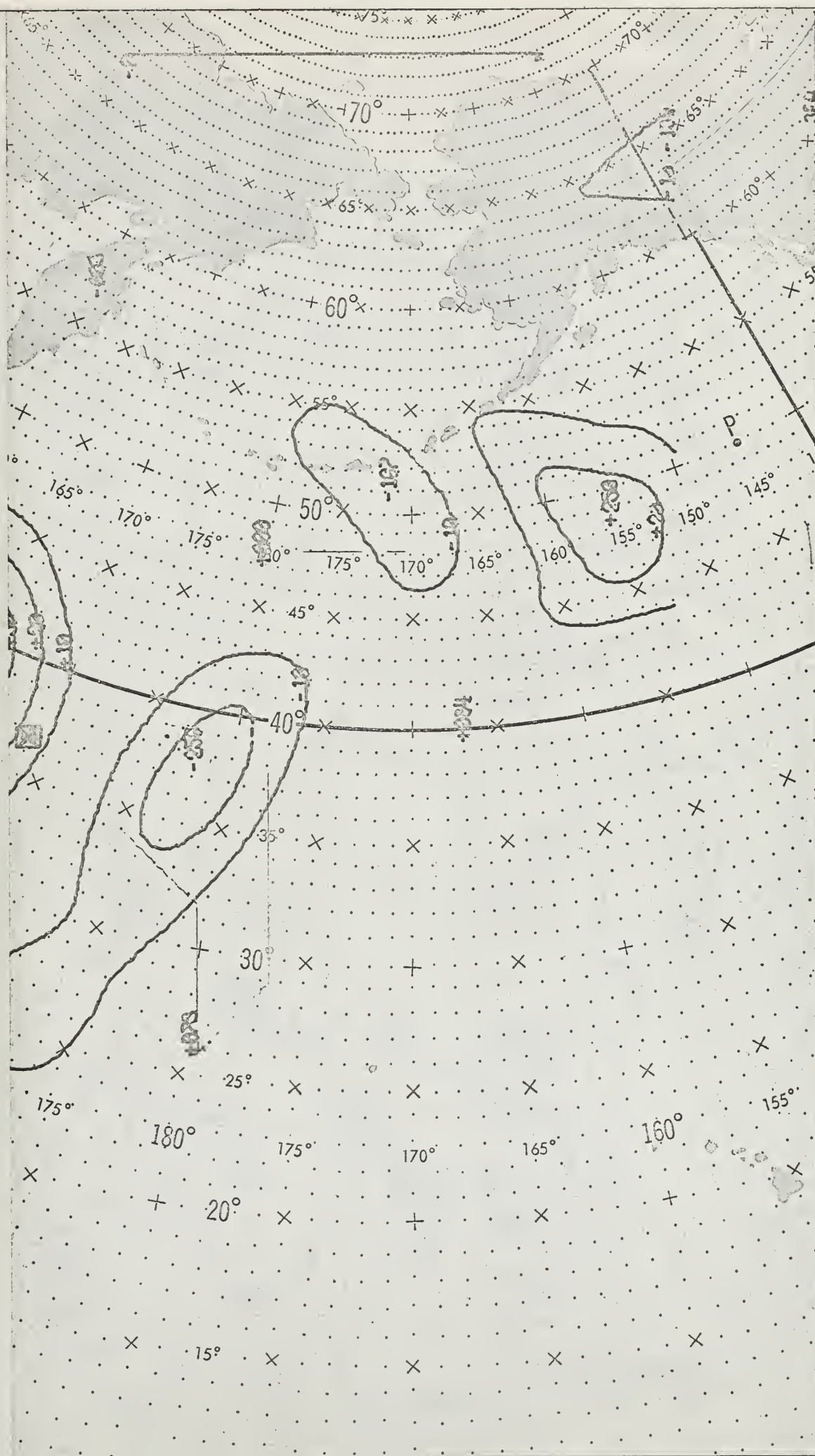
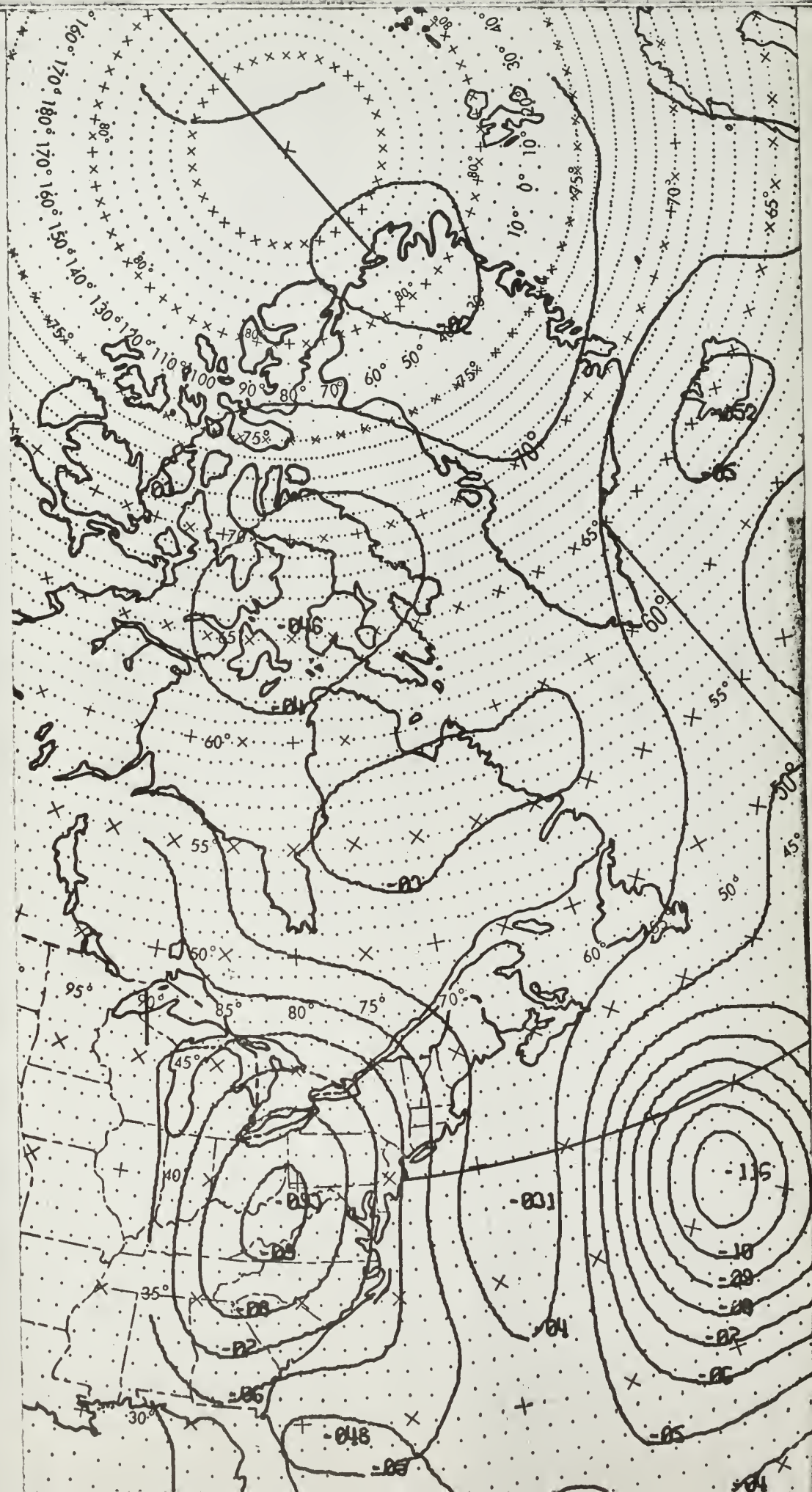


Figure 18 σ_w 500' Pacific



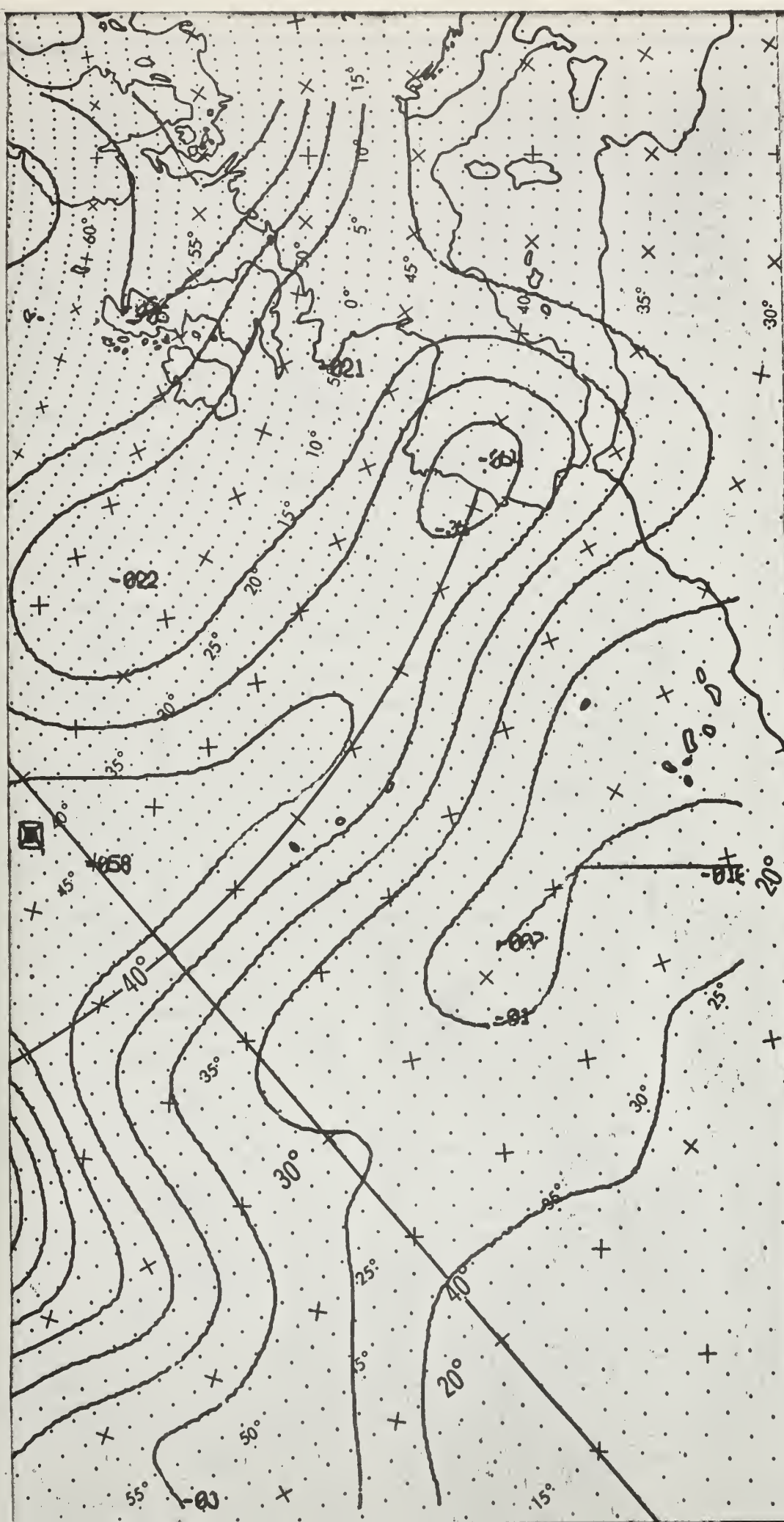
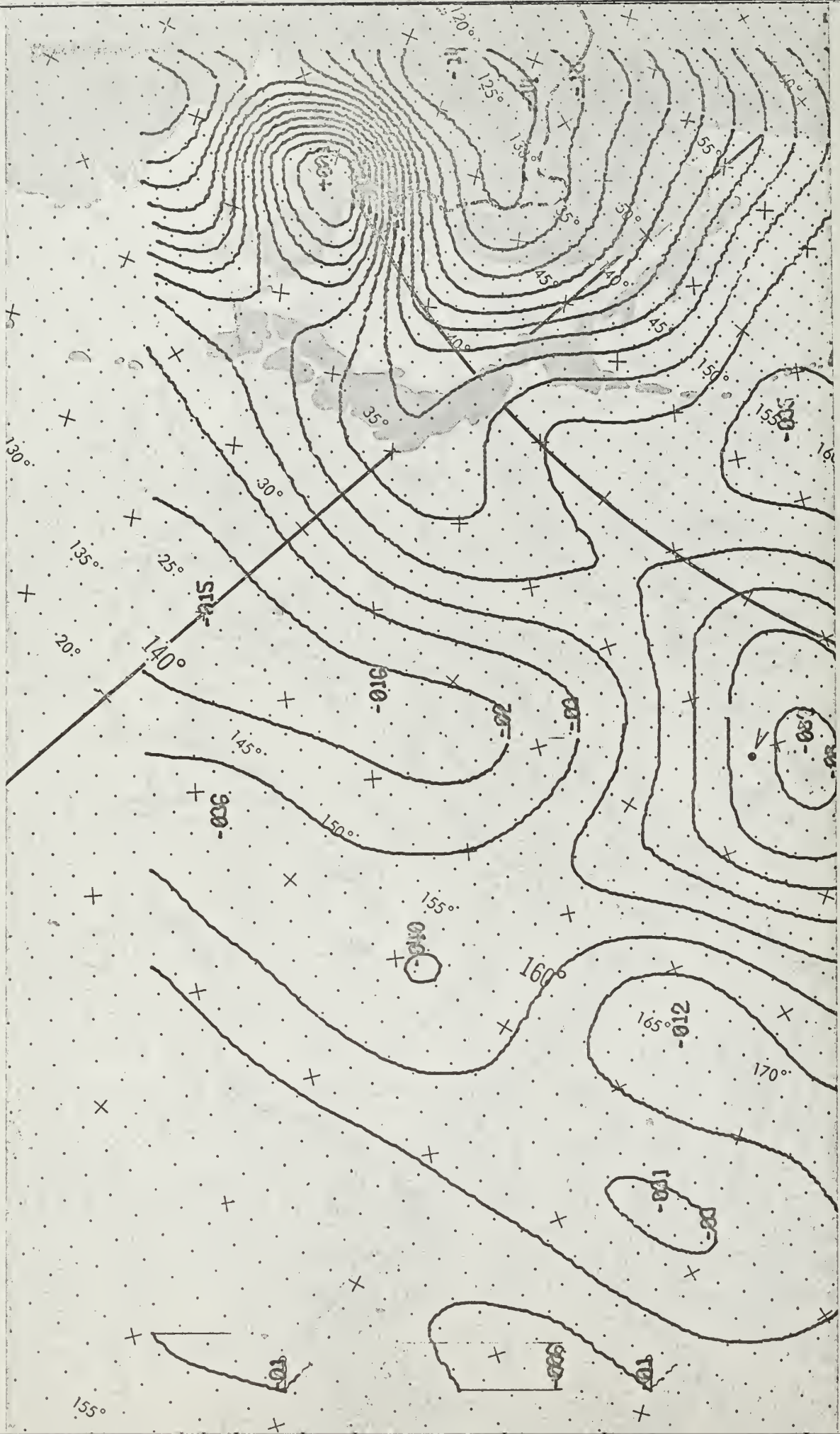


Figure 19 Total heat exchange, Q_n , Atlantic



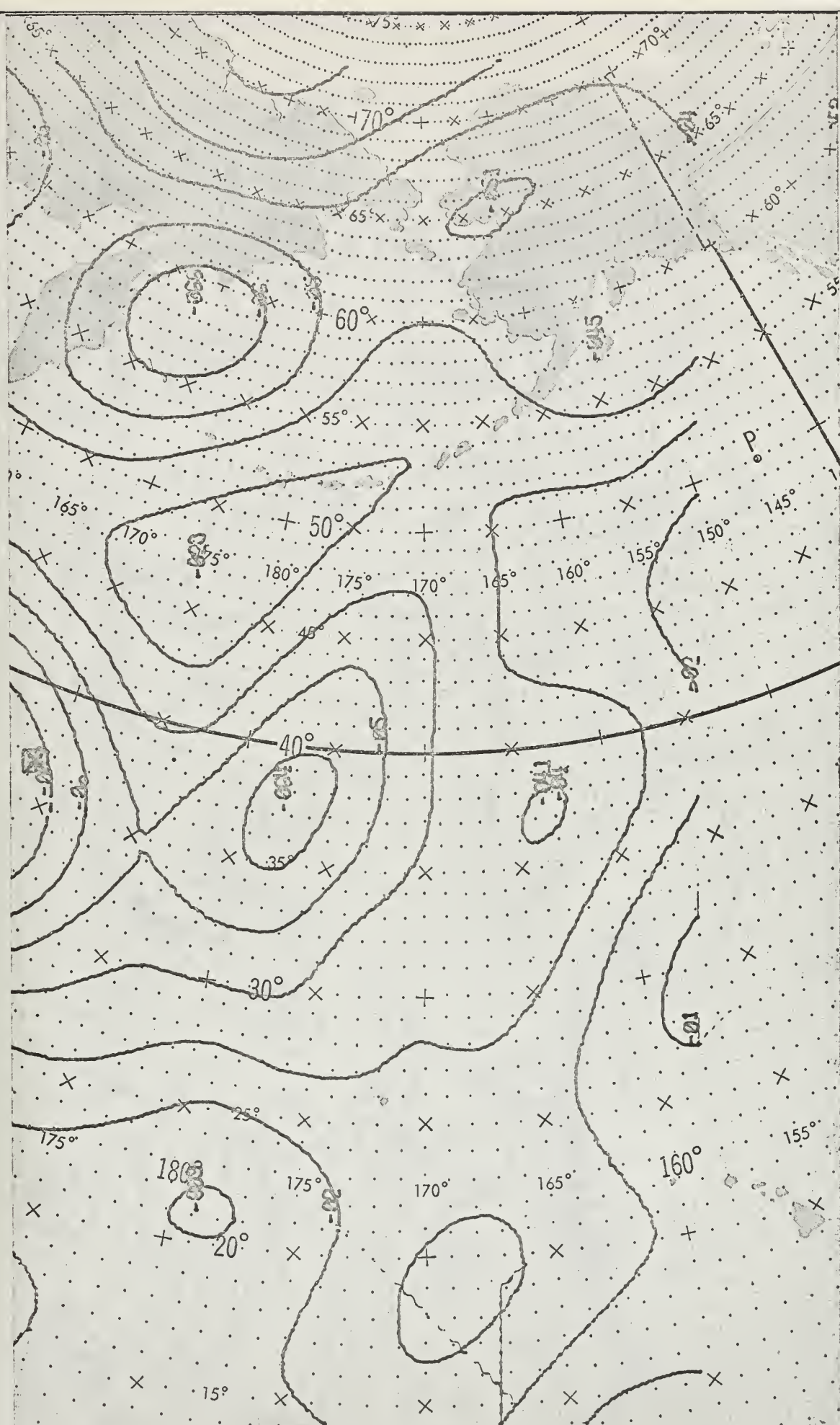
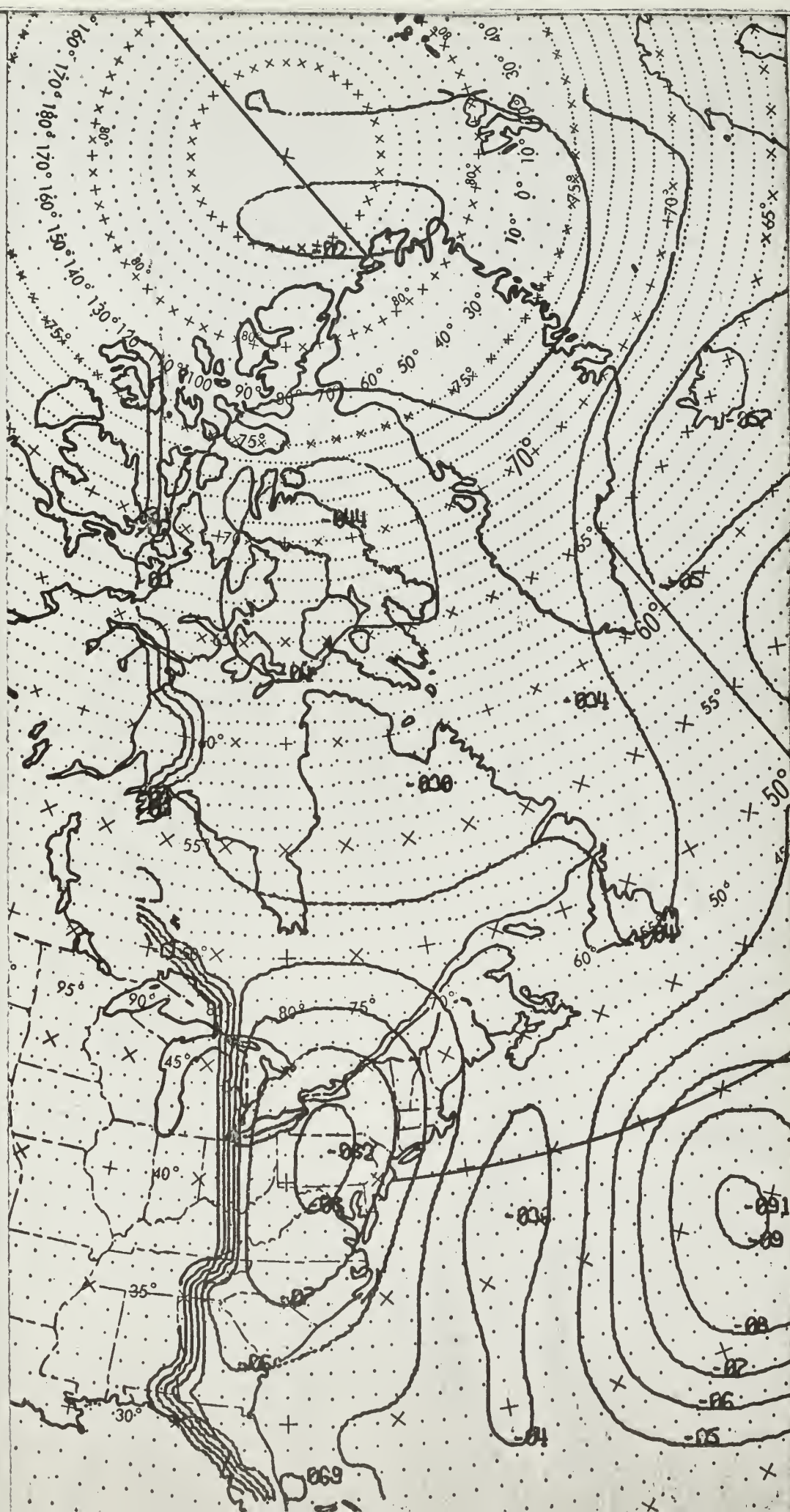


Figure 20 Total heat exchange, Q_n , Pacific



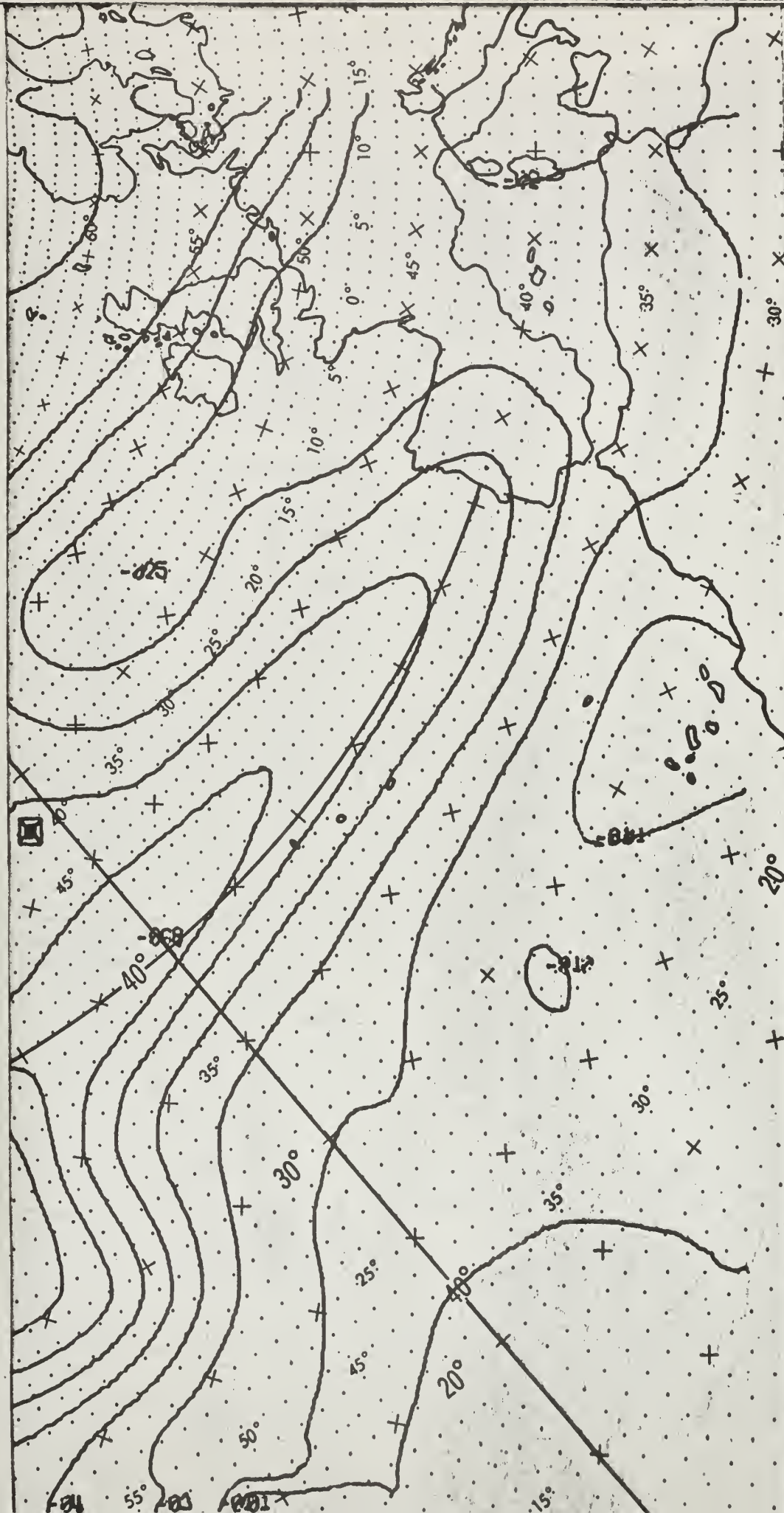


Figure 21 Mean Heating term, \bar{H} , Atlantic



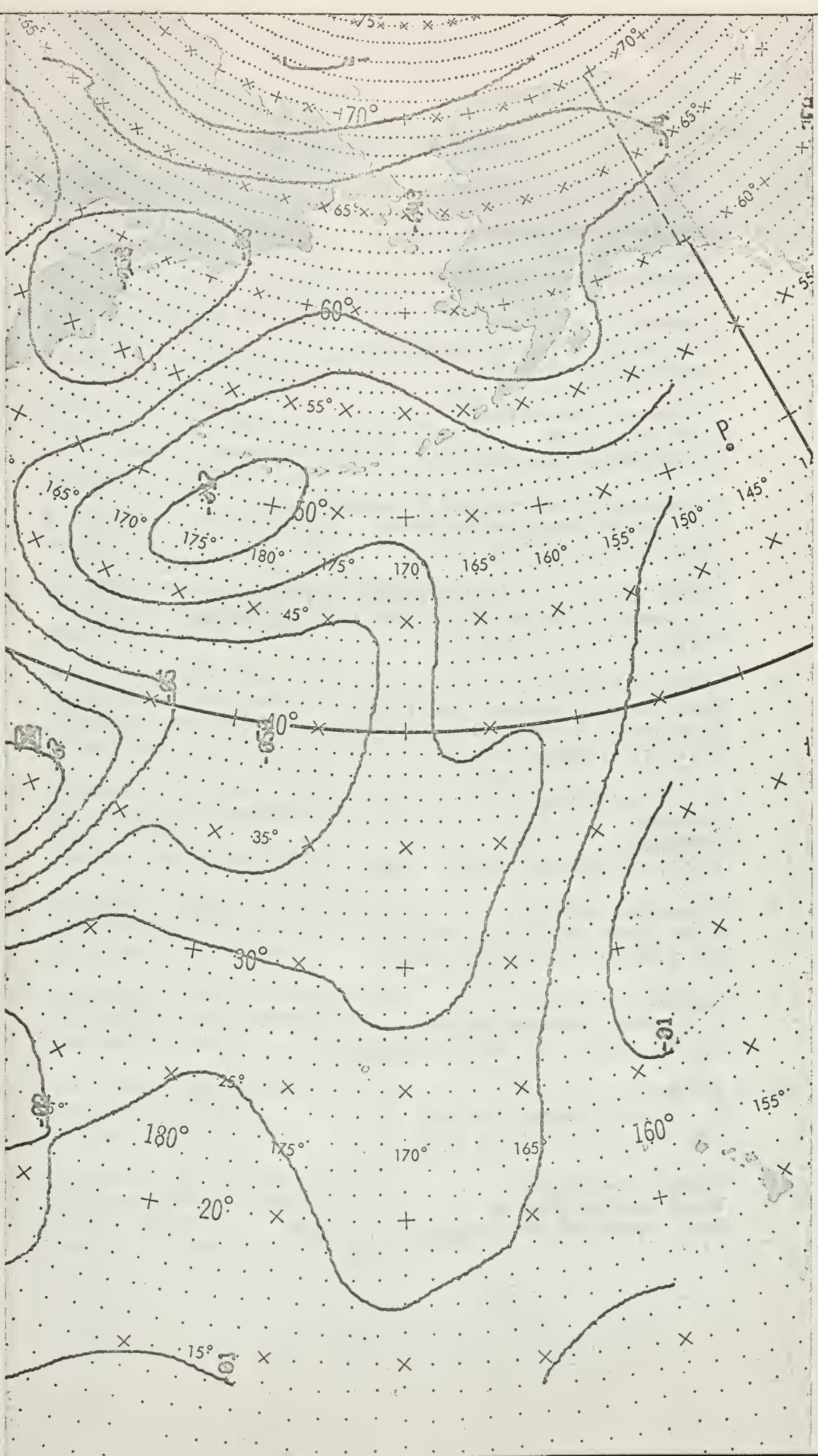


Figure 22 Mean Heating term, H, Pacific

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13. ABSTRACT A correlation analysis of a thickness tendency equation including heating and vertical motion terms was carried out. One of the main purposes of the investigation is to provide a firmer foundation for a 1000-500 mb thickness forecast scheme. A large data sample was used and single and multiple linear coefficients were calculated. These were computed for a wintertime situation with separate analyses for Atlantic and Pacific areas. The resulting correlation coefficients for the advection, vertical motion and heating terms gave substance to the hypothesis that the observed change in thickness may be fairly well approximated by the change due to horizontal advection only. The vertical motion term gave a smaller but significant correlation, while heat exchange terms did not correlate significantly.			

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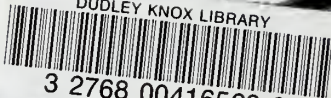
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